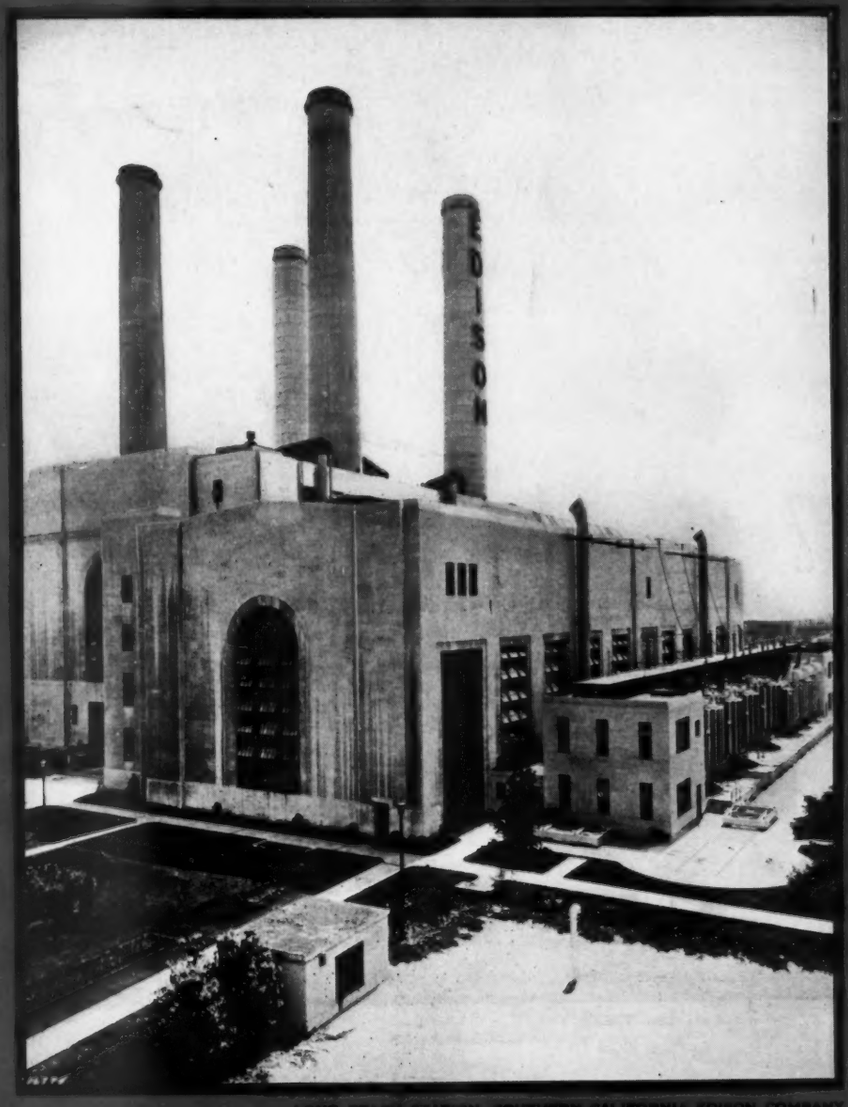
COMBUSTION

3 5 193

Vol. 2, No. 8 FEBRUARY 1931 25c. a copy

Engineering Library



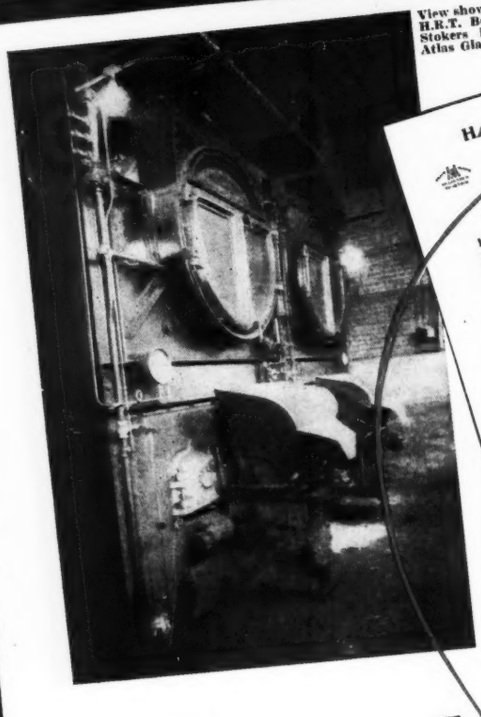
LONG BEACH STATION, SOUTHERN CALIFORNIA EDISON COMPANY

Considerations in the Design of the Small Boiler Plant
By JOSEPH BRESLOVE

The Chemical Nature of Coal
By Professor WM. A. BONE

Other Articles in This Issue By

A. R. MOBERG • WM. L. DEBAUFRE • DAVID BROWNLIE • C. H. S. TUPHOLME • R. C. VROOM



View showing the Walsh-Weidner H.R.T. Boilers and the Type K Stokers installed at the Hazel Atlas Glass Co., Wheeling, W. Va.

HAZEL-ATLAS GLASS COMPANY

WHEELING, W. VA. May 27, 1930.

Mr. R. L. Lindsmith,
Combustion Engineering Co.,
First National Bank Bldg.,
Pittsburgh, Penna.

Dear Sir:-

The two 125 H.P., C. E., Premier Boilers with Type K stokers purchased from you to replace the two cast iron, hand fired, sectional heating boilers and one vertical fire tube boiler for generating steam for process work, were placed in service at our Wheeling Plant during November of 1929.

We found upon making an analysis of the fuel costs for the first quarter of 1929 we used 708.28 tons; during the first three months of 1930 we used 490.90 tons;- a difference of 217.38 tons.

We have by this installation accomplished:-

(a) a saving in fuel.
(b) the elimination of smoke and are able to maintain uniform steam pressure, which is important in heating and process work.

Yours very truly,

HAZEL ATLAS GLASS COMPANY

217 *tons less coal*

the first quarter of this year as compared with last year

Two Hundred Seventeen tons less coal for the first quarter of this year, as compared with the same period of last year, is a considerable reduction in fuel for firing two 125 hp. units.

Combustion Engineering Corporation's fuel burning and steam generating equipment for small industrial plants, will effect savings just as worthwhile, in proportion to the steam generated, as for the large central station plants.

A catalog illustrating and describing the Type K Stoker (for boilers up to 200 hp.) is available and will be sent upon request.

COMBUSTION ENGINEERING CORPORATION
200 Madison Avenue **New York, N. Y.**

Boilers · Air Preheaters · Stokers · Pulverized Fuel Equipment · Water-Cooled Furnaces

Orders covering two units similar to the above have since been received from the Hazel Atlas Glass Company

COMBUSTION

VOLUME TWO • NUMBER EIGHT

CONTENTS FOR FEBRUARY 1931

FEATURE EDITORIAL

Steam-Generated Electricity Sets Records Despite 1930 Conditions — *by Wm. M. Carpenter* 15

FEATURE ARTICLES

Considerations in the Design of the Small Boiler Plant — *by Joseph Breslove* 17
The Chemical Nature of Coal — *by Professor William A. Bone* 24
Blow-Down Losses and Their Correction — *by A. R. Moberg* 26
Thermal Properties of Gaseous Mixtures — *by Wm. L. DeBaufre* 29
European Practice in Boiler Feed Pump Drives — *by C. H. S. Tupholme* 34
Combined Burners for Firing Waste Fuels — *by R. C. Vroom* 37
The Removal of Sulphur from Chimney Gases — *by David Brownlie* 45
How to Compute Stack Sizes — *by B. J. Cross* 50
Progress in Smoke Abatement 52
Third International Conference on Bituminous Coal 53
Program—Fifth Midwest Power Engineering Conference—Fourth National Fuels Meeting 54

EDITORIALS

Automatic Control—A Present-Day Necessity 16
What About 1931? 16

DEPARTMENTS

NEWS—Pertinent Items of Men and Affairs 55
NEW EQUIPMENT—A New Boiler Feed Pump Governor, Steam Gage for High Pressures and Temperatures, A Small Roller Type Pulverizing Mill 56
NEW CATALOGS AND BULLETINS 58
ADVERTISERS IN THIS ISSUE 63

CHARLES MCDONOUGH, *Business Manager* — CARL STRIPE, *Editor* — H. STUART ACHESON, *General Representative*

COMBUSTION is published monthly by In-Ce-Co Publishing Corporation, a subsidiary of International Combustion Engineering Corporation, 200 Madison Avenue, New York. London office, Africa House, Kingsway, W.C. 2. W. R. Wood, President; George H. Hansel, Secretary; W. I. Branigan, Treasurer.

SUBSCRIPTIONS, including postage, United States and Canada, $2.00 a year, Great Britain 8 shillings. Other countries, $3.00. Single copies: United States and Canada, 25 cents.

COPYRIGHT, 1931, by In-Ce-Co Publishing Corporation, New York. Printed in U. S. A. Publication office, 200 Madison Avenue, New York.

Sirocco Mechanical Draft Equipment

. . *Standard of the World*

To Power Plant and Consulting Engineers, Power Plant Executives *and* Operators

The American Blower Corporation, manufacturers of mechanical draft equipment since 1881, maintains branch offices in all the principal cities of the United States.

Each office is in charge of competent engineers who have a thorough knowledge of the correct application of fans to power plants. And each branch office is a real service organization that will be glad to aid you in the application of forced or induced draft equipment, or in laying out the specifications for such equipment.

Of course there is no charge or obligation. It is just another American Blower service that is available to engineers. Phone or write the nearest American Blower Branch Office.

AMERICAN BLOWER CORPORATION, DETROIT, MICH.
CANADIAN SIROCCO CO., LIMITED, WINDSOR, ONTARIO
BRANCH OFFICES IN ALL PRINCIPAL CITIES

(1069)

American Blower

VENTILATING, HEATING, AIR CONDITIONING, DRYING, MECHANICAL DRAFT
MANUFACTURERS OF ALL TYPES OF AIR HANDLING EQUIPMENT SINCE 1881

SIROCCO—STANDARD OF THE WORLD

COMBUSTION

VOLUME 2 . FEBRUARY 1931 . NUMBER 8

Steam-Generated Electricity Sets Records Despite 1930 Conditions

WM. M. CARPENTER

IN spite of the depression, the production of electricity by steam in 1930 was even greater than it had been during the boom year of 1929 and set new high records not only for total output but also for fuel economy. All of the decrease which has marked last year's generation of electricity has taken place in hydro-electric plants, as a result of diminished industrial demands and of the extraordinary and continuing drought in several of the important water-power regions of the country.

As a result of the continued installation of new generating stations of the most modern design, the addition of further units to existing plants and the improvement of load factor in others, the average production of electricity per pound of coal is now higher than ever before. Preliminary estimates set a figure of 1250 kw-hr per ton (or, in other words, of 1.60 lb. per kw-hr) for the overall performance of 1930 as compared with an average of 1185 kw-hr per ton (or 1.69 lb. per kw-hr) the year before. This is an increase in efficiency of more than five per cent and once more the electric light and power industry has been able to perform the feat of producing more energy than it did the year before and of using less fuel to do it with.

Throughout the great industrial areas of Pennsylvania, Maryland, and West Virginia, hydro-electric enterprises were, last year, beset with extraordinary difficulties. All along the northern half of the Atlantic seaboard many of the rivers, which hitherto had furnished large quantities of water-power, practically disappeared, and in several cases their reservoirs had to be drawn down to relieve navigation and sanitary conditions on the lower reaches of the rivers.

Although unheralded as factors in "drought relief," the steam plants of these regions took over, as a matter of course, the loads which the water-power plants could no longer handle and, while there were several instances of the unusual spectacle of steam-generated electricity feeding backward over transmission lines to take the place of what had hitherto been regarded as uninterruptible hydro-electric supply, no impairment of service was felt by any consumer at any time.

During the coming year there is every indication of a further increase in the demand for steam-generated electricity. In spite of the fact that it is not so evident to the casual observer, the drought is still with us with uninterrupted severity and water-power during 1931 will probably show still further declines.

With the revival of business activity, the industrial load will shortly begin to increase and the country's steam plants will be called upon to produce greatly increased quantities of power. Because of the continued pressure for lower electric rates, they will be expected to produce it at the lowest possible costs and the rewards for continued improvements in fuel efficiency have thus become more promising than ever.

Wm. M. Carpenter

ECONOMIST

National Electric Light Association

EDITORIAL

Automatic Control — A Present-Day Necessity

IN power generation, the efficiency of steam utilization is determined almost entirely by the design of the turbo-generator. With constant steam pressure, and temperature at the inlet and constant vacuum at the exhaust, the efficiency of operation is determined by the design of the machine,—built into the unit—and, if the equipment is in proper condition, the efficiency for each load is constant. Since the performance of the unit is inherent in the machine itself —wholly independent of the human element—the average operating efficiency practically equals the test efficiency. No matter who opens the throttle valve, chief engineer or oiler, the final result is the same, close to the maximum attainable.

Unfortunately, the steam generating plant has not been as successful in eliminating the handicaps of human influence.

While the designers of steam generating units have provided for high efficiencies, these results are only potential and usually they are possible only under the careful supervision typical of test conditions. In average operation, the performance is definitely below the maximum and the gap between the actual obtained efficiency and the maximum possible efficiency widens with the extent to which the human element contributes to the result.

It is obviously impossible for any operator to observe and interpret each fluctuation in load, pressure, temperature and draft and to adjust the feed rates of fuel, water and air to meet exactly each changed condition.

The most alert and capable operator can only hope to approach ideal conditions, for even if his corrective measures were exact, there would still be a lapse between the beginning of the faulty conditions and the time when they were discovered and the remedy applied. Furnace conditions often become pretty bad before they are discovered and the operating efficiency falls off appallingly in the interim.

Then there are the careless and inattentive operators—the unfaithful stewards. Naturally there is a time lapse before these laggards are discovered and weeded out of an organization.

At its best, manual control of steam generating equipment is inadequate. At its worst—the hazards and waste are little short of criminal.

The remedy is simple and certain.

Automatic control is available to meet every combination of fuel, firing method and load condition. The apparatus has been highly developed and is reliable, low in first cost and easy to maintain. The results are uniformly gratifying and in many instances, the savings have been tremendous.

Automatic control in the boiler room will improve the overall efficiency of steam generation in the same way that the complete mechanization of the turbine room has raised the standards of steam utilization.

What About 1931?

THE past year marked one of the most disheartening business depressions of modern times, the effects of which have extended to every industry, to every class of people and to every country in the civilized world.

The more serious minded who prefer facts to fancies can analyze the recent depression as the inevitable reaction to a long-continued inflation during which a condition of false prosperity was established and nourished by the general unwillingness to accept facts and to the belief that there was no limit to the consuming power of the American public. The experience of the past year was a dramatic demonstration of that homely law, "Whatever goes up, must come down."

And down they came to set new lows which now offer unprecedented opportunities for investment and sound financing. The pendulum of business swung low and it has reached the very bottom of the arc but in so doing it has gained tremendous inertia for the upward swing which is now beginning.

If a man should stand exactly at the south pole, every direction he turned would be north. Business stands in a comparable position today — in every direction it is pointed upward.

Physical conditions are ripe for the climb back; however, there are two human factors both of which are essential to our return to normalcy and "good times."

The first is confidence—confidence in ourselves, our associates, our organizations and our country.

The second is application—giving a little more to our jobs than ever before and trying a little harder to create a measure of extra value in whatever work we do.

1930 took much and gave little.

1931, on the other hand, will be a year of opportunity. A year in which "he who gives most will profit most."

Considerations in the Design of the Small Boiler Plant

By
JOSEPH BRESLOVE
Consulting Engineer, Pittsburgh

The author has had a particularly broad experience in the revamping of existing plants and the designing of new plants. For the purpose of discussion, he roughly classifies as small boiler plants those consisting of boilers up to 500 or 600 rated horsepower when producing steam for industrial purposes, and boilers up to approximately 100 horsepower when used primarily for heating purposes. The comprehensiveness with which the subject is treated will necessitate its publication in three parts, of which the present article is Part One. This article begins with a brief review of major developments affecting the design of steam plants and a survey of past practice with particular reference to the small plant. The author then discusses the various types of equipment entering into the design of the typical small boiler plant of today and the factors which determine the proper selection of equipment and the general design under various conditions. Subsequent articles will complete the discussion of equipment, and present detailed analyses of design considerations, costs, etc., in connection with a number of actual installations. . . . So much emphasis has been placed on developments which are primarily applicable to medium-size and large steam plants, that the problems of the small plant have not received their proper share of attention. The Editor of COMBUSTION takes pleasure, therefore, in presenting this able and up-to-date survey of the small plant, its problems and the opportunities that exist for improving practice in this important section of the field.

IT is with some temerity that one ventures into the field of the small or medium-size plant with the thought that it is of sufficient interest to merit consideration from other engineers, or the principals whom they represent. Engineering accomplishments have come about with amazing rapidity in recent years but in no instance have they changed to such an extent as in the general conception of engineering practice in the modern power house boiler plant. Units of record size in superpower stations have come into being and literally revolutionized our earlier ideas of capacity and economy. The electric generating unit has kept pace with the steam generator but its march has not been so spectacular. It is true that the capacity and economy of steam turbine generators are outstanding features but the designs are not so radically different from the smaller units which obtained a few years back. It is in the boiler house that the greatest changes have come about in the sense of departure from previously accepted practice.

The advent of the large power station, remarkable efficiency in the burning of fuel, increased numbers of hydro-electric plants, and wide-spread transmission lines, have resulted in electrical power rates which are very attractive to the average consumer. But there still remain many industries which can manufacture their own power with a net saving over all fixed and operating charges. Other plants which must produce steam for heating and process work vary in size from the small one of 50 hp. to the fairly large station of 3000 hp. It is this range with which we will concern ourselves. To place an arbitrary line of demarcation between what may be termed a large plant and a small one; or to state that a certain size boiler should be rated under one heading or the other is difficult, but for the purpose of discussion we might term a 500 or 600 hp. boiler a small unit for general industrial purposes and a 100 hp. boiler a small unit where little more than heating is required.

The industrial plant using steam for power, heating, and process work generally contains two or three boilers, ranging in capacity from 300 hp. to 600 hp. each. These sizes suggest an arbitrary line of classification, for they readily adapt themselves to a particular type of firing. Except in special instances, a single retort, underfeed stoker may be used for bituminous coals and a chain grate or overfeed type stoker for semi-bituminous coals or where free-burning, non-coking coals are available. For the very small plant requiring not over 100 to 200 hp., hand-firing is much in evidence. This, however, is rapidly giving way, and rightfully so, to stoker-firing, since boilers of this size may be more economically fired by one of the many small stokers now on the market. They may be single retort underfeed with dump plates, screw feed with center retort and dead plates, overfeed type, or the so-called hand stokers; depending upon fuel and load conditions.

Since the present discussion does not concern itself with the determination of whether power should be bought or manufactured, but merely with the general features covering the small or moderate-size plant, and particularly with the boiler room, we may confine ourselves to the factors entering into its life. Where steam is not required for process work and where the heating requirements are seasonal, it is

difficult to justify a private power plant, but where the heating conditions are of some magnitude it may be desirable to include power generation even where low power rates are available. Where the power consumed is not great in proportion to the steam requirements but operation of a boiler plant for heating is imperative, the private plant may be the proper solution. However, where the demands for steam and electric power balance, there can be no difference of opinion and it is generally admitted that power should be manufactured by the private plant. In some cases, high pressure steam may be used in a bleeder-type steam turbine with the process and heating steam bled from the turbine in accordance with the demand. Or if only low pressure steam is desired a non-condensing engine or turbine may be used exhausting directly into the heating and low pressure main.

The general design hinges largely upon these two factors. If the plant is to be used exclusively for heating and, therefore, seasonal in its operation, its initial cost must be low even at the sacrifice of some efficiency in operation. On the other hand, if it is to provide both power and process steam, or process steam and heating, involving every-day operation, certain refinements are justifiable and the greater initial cost may show dividends due to increased economy. Modern boiler room accessories may each, individually, be capable of showing a decrease in fuel and operating costs, but the total output of the station may be inadequate to absorb the added investment charge of the apparatus. This thought is not new; in fact, it is familiar to all engineers. But it is worthy of being emphasized for in their desire to emulate the practice of larger stations many engineers are apt to burden the small plant with charges that cannot be justified. There are styles in engineering, even as in women's clothes, but they must not be followed blindly in the design of the small plant. In the ultimate, it may not be so much what to do as what not to do.

Boiler Plants of the Past

The small heating plant probably ranks among the most inefficient of stationary installations. The old conception of such a plant was that it consisted of one or more return tubular boilers, attended by firemen whose principal responsibility it was to see that the steam pressure was kept at a certain point and that the water gage did not drop too low. The sole incentive to good firing was based on the saving of muscular effort in the quantity of coal wheeled from the storage pile and thrown into the furnace. In justice to these men, however, it should be said that there were a number who were excellent firemen and obtained splendid results under the conditions. The boilers were low set, usually had leaky settings and were served by short stacks, resulting in insufficient draft, much smoke, and unburned coal in the ash pit. It was impossible to carry more than 75 to 100 per cent of rating and therefore two boilers were used frequently where one should easily have served the purpose. The steam piping in these plants consisted essentially of many short bends and screwed joints, uncovered piping, and steam leaks in direct proportion to the number of joints. The piping system usually had grown like Topsy, and it was difficult to trace its source or destination. An excellent, but not unusual, example of this may be seen in Fig. 1. (Fig. 2 shows the same plant after rearrangement.) Boiler feeding was handled by a small

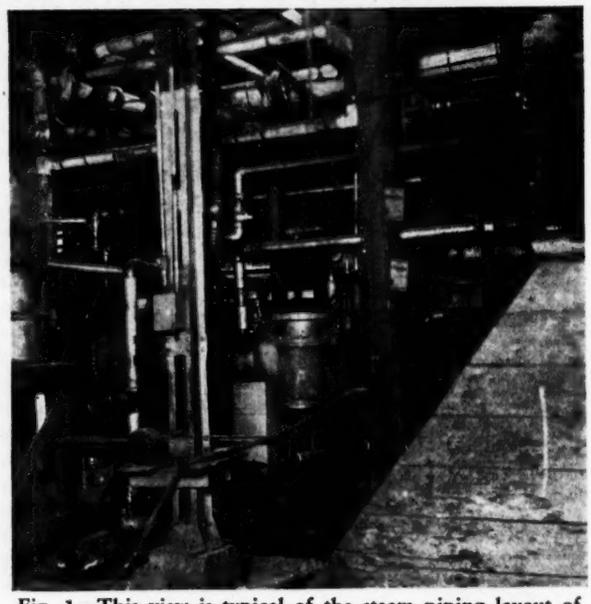


Fig. 1—This view is typical of the steam piping layout of old plants. Short bends, screwed joints and lack of insulation and orderly layout contributed to plant inefficiency.

reciprocating pump, usually too small for the capacity and therefore operating at high speed with considerable slip. In most cases, cold water was fed to the boilers or a homemade feedwater heater served to utilize a small portion of the exhaust steam from the engines or the boiler feed pump. Coal was wheeled from the storage pile into the boiler room and ashes handled in the reverse direction. The pressure gage was the only instrument in evidence. Soot was blown from the tubes with a hand lance on infrequent occasions and scale removed when it had grown to such proportions as to jeopardize the generating capacity of the boiler.

This boiler room seems like a far cry from the ideal which obtains today, but it served its purpose in times of extremely cheap fuel, low labor costs, and a less competitive field for the company's product. Nevertheless, the picture is not exaggerated and there are many plants to which the description still applies.

The larger boiler plant presented a somewhat different picture, but did not depart from it sufficiently to make it strange or unfamiliar. The boiler units were usually two or three in number, rating from 250 to 400 hp. Some of these were hand fired, but a few were equipped with stokers, either chain grate,

overfeed or the early types of underfeed stokers. A large proportion of the latter were without dump plates and, therefore, necessitated hand cleaning with all its attendant losses and evils. Low settings were standard, limiting the capacity, and even a small additional load usually meant another boiler. In one particular case it was found difficult to carry a growing load with five 150 hp. boilers in a row. The old idea, and a certain type of salesmanship, resulted in the purchase of two additional 150 hp. units, making seven boilers in all in a plant where the average load was about 700 hp.

Boiler Plants of the Present

Number of Units: The total load will, of course, determine the capacity to be installed, but the load variations and the method of firing are intimately tied up with it. Where the plant is small and a short shut-down is not serious, one boiler may safely be considered. This will serve for a time until the load is increased or commercial conditions warrant an additional unit. The size of the unit should be determined primarily by its capacity to take care of the load with only one unit in operation. Only under extreme conditions are the losses of two units justified, unless peak loads are encountered for lengthy periods when two units become a necessity. This allows one unit to be held as a spare. In general, if a shut-down of small duration does not involve a manufacturing loss of some magnitude it is fairly safe to operate with but one boiler, and many plants are doing this, but where a shut-down becomes a serious matter two units must be installed. There will be cases where three units are justified, but this is a matter where commercial as well as engineering considerations must be the determining factors.

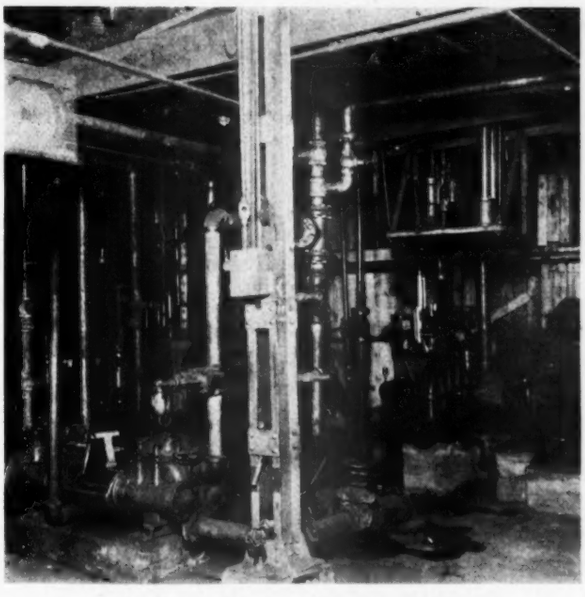


Fig. 2—View of plant shown in Fig. 1 after rearrangement of piping.

Type of Boiler: The type to be used is open to a wide choice. If the steam is for heating purposes only, and the distance of steam distribution is not too great, low pressure boilers may be installed. These follow a well defined trend and bear a family resemblance, but there seems to be a growing inclination, and rightfully so, towards the welded steel boiler, excepting in the smallest sizes. For the larger installations, and where steam is required for purposes other than heating, the horizontal return tubular boiler still presents many admirable features of simplicity, reasonable first cost and low upkeep. In sizes up to 100 hp., they may be of the "Economic" or self-contained type requiring very little or no brickwork. This simplifies the installation and permits removal of the boiler to another location. The desirable limit of the h.r.t. boiler is in the neighborhood of 150 hp., but exceptional cases may warrant a unit of 200 hp.

The cast-iron heating boiler is built for 10 to 15 lb. pressure and the steel boiler for pressures up to 150 lb. The latter pressure may not, at first, be the actual working pressure but it permits the addition of a small steam engine at a later date and also allows a margin of safety for the reduction in pressure which inevitably comes into the later life of the tubular boiler.

The unit for the industrial plant presents a much wider degree of choice. The proponents of the different types all have legitimate reasons for their preference. With the advent of the large boiler manufacturer, turning out two or more diverse designs, the arguments against one design or the other are not given the same emphasis. This is correct, for the factors influencing the choice are many, not the least of which is a prejudice in favor of one particular class. To the user of straight tube boilers, the bent tube may be anathema or the devotee of the bent tube type may be appalled at the thought of removing the many handhole covers from the straight tube unit.

In general, space requirements become the first consideration. Frequently, the new unit is to be installed in the space occupied by older units and it will usually be found that one type "fits" much better than another. In fact, it is fortunate that a type can be found to make the most of the available space. Building costs are thereby greatly reduced and much time saved. It is generally conceded that the bent tube or vertical type is a more rapid steamer than the horizontal, but in the average small plant where violent fluctuations or extreme ratings are not encountered this feature is not so important; nor does the controversy over the question of restricted circulation enter seriously into the situation. The height of the building may accommodate a horizontal boiler but the width not permit easy removal of tubes. In such cases, it will usually be found that a bent-tube type will fit in between the building trusses and allow for side removal of the tubes. The

steam piping thereby becomes somewhat more difficult of access, but not seriously so. Considerable emphasis on certain features is placed by the advocates of the various types, but the experience of years with many different designs leads the writer to the belief that for ordinary industrial work, having decided upon the type which best fits the space conditions, the element of personal prejudice may be safely catered to without much risk or difficulty.

The bent tube boiler requires less floor space, is a more rapid steamer, has no hand holes that require removal for cleaning; may be built with as few as two drums and therefore at a price under the conventional horizontal type, and in general the cost is less. For high ratings and bad water conditions the two drum boiler, however, is apt to prime over very easily and three or four drums are preferable. As a generic type, the bent tube boiler is more flexible to the ideas of the designer and many com-

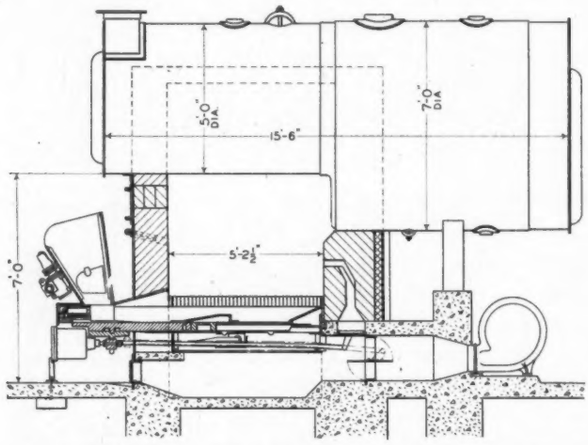


Fig. 3—Typical of modern practice in the small plant is this 125 hp. h.r.t. boiler fired by a center-retort underfeed stoker.

binations of drum and tube arrangement are possible. It requires more head room for installation and while lower in cost, the brickwork usually costs more. Tube removal is more difficult but does not require the space in front or rear necessary for removal of tubes from a horizontal boiler. Where the boiler room is narrow and a coal bunker is used it is frequently impossible to consider any but the bent-tube type.

The horizontal straight tube boiler may be built up with sectional headers or the conventional box header. For low ratings, the longitudinal drum is permissible, but for higher ratings only the cross drum should be considered. Even with high settings the horizontal boiler requires less headroom. It is usually more costly but the brickwork is less expensive than with the bent tube type and tube removal is comparatively easy. The box header boiler has the great advantage of being susceptible to complete fabrication and assembly before shipment so that where the time element is of great importance, space conditions peculiar, or the labor market unusual, it is sometimes found advantageous to have it completely assembled before shipment. Installation is then a comparatively simple matter and much time saved.

It cannot be over-emphasized that any inherent preference for one type over the other, either by the operating crew or the owners, should receive a sympathetic ear from the engineer in charge of the development. We have passed the stage when only one type is the solution to the problem.

Steam Pressure: In dealing with the industrial power plant, we are more likely to encounter the problem of revision of an existing plant, which has become uneconomical or obsolete, than that of designing an entirely new one. Existing plants have usually operated under low pressure, without superheat, and selection of the new pressure is sometimes difficult.

Steam pressures have increased enormously in recent years; high pressures have come to stay, and for the large station with expert engineering attendance the limit becomes purely that of commercial economy. In the small station the extreme condition is much more quickly reached. Where process steam is involved or if there is any prospect of the addition of generating equipment, pressures up to 600 lb. per sq. in. may be desirable, but otherwise pressures over 250 or 300 lb. are questionable. This limit is not due to inherent difficulties in design or operation but rather to the rapid increase in cost over the economies to be effected. In many existing plants, the steam and water piping from the boiler out is "extra heavy" or already suitable for operation up to 250 lb. The additional cost over a boiler built for but 150 lb. is not great and since the piping system is suitable for 250 lb. the additional investment may become justified through future conditions. A sharp line of demarcation is reached here, for the boiler, piping, valves, and other auxiliaries become of a different order beyond the 250 lb. line. This statement must be taken in a broad sense, for in some of the more recent plants under discussion, pressures from 400 to 600 lb. have been found desirable. These pressures permit the installation of extraction turbines for use with process steam. It will be found, however, that the great majority are in the class where 250 lb. pressure will be the maximum for many years insofar as it applies to that particular plant, and the increased cost for equipment beyond this point is not warranted.

System of Firing: The writer's experience has been more intimately identified with plants using bituminous coal, such as is found in the Pennsylvania field, West Virginia, Eastern Ohio, and Eastern Kentucky, sometimes grouped under the heading of Pittsburgh coal, but to a less extent has also involved the use of free burning, non-coking coals of Illinois, Iowa, Kentucky and Indiana. The coal to be burned and the load conditions are the basic factors in the determination of the type of firing, and for this

reason, a certain type of stoker may predominate in one territory. The chain grate and overfeed stoker had a wide field for many years, but with higher ratings, larger units and lower grades of coal the underfeed stoker has had increasing popularity and has now displaced the other in many sections of the country. Ratings as high as 300 per cent with low B.t.u., high ash coals may be carried on forced draft, chain grate stokers with air zoning if care is taken to install sufficient grate area and this type is much in evidence with the use of free burning, non-coking coals and similar grades of fuel.

For the bituminous fuels, both high and low volatile, however, the underfeed stoker, in some form, is rapidly displacing all others. The original underfeed stoker, without dump plates, was a distinct improvement over hand firing. It eliminated smoke, reduced boiler strains, permitted increased ratings and made the work of the fireman less arduous, but it was still necessary to clean fires and remove the ash from the grates. This was sometimes extremely difficult with highly clinkering coals which formed large masses due to insufficient agitation of the fuel bed. The advent of the modern underfeed stoker with agitating mechanism and air zoning was a distinct advance in the art and it probably more nearly fits average requirements than any other type. The center retort with side dump for smaller boilers, and the multiple retort underfeed with end discharge for large boilers and high ratings, dominate the power field. Since we are concerned with the small boiler installation, upon which was placed an arbitrary size of 500 or 600 rated hp., the type of stoker becomes easier of choice, that having been one reason for choosing such size as the limit of this discussion.

The single retort underfeed stoker is particularly adaptable to the small and medium-size boiler. It may be steam driven or electrically driven, depending on the local conditions. It requires no basement, which materially reduces the building cost. It is easily operated, maintenance is low, it can handle a wide variety of coal, and is flexible over widely fluctuating loads up to 200 per cent of rating, and 250 per cent for short periods. It is responsive to operation on loads as low as 25 per cent of rating and has a low fuel consumption for banking fires and starting. In one particular plant, a 400 hp. boiler equipped with 93 sq. ft. of grate surface requires 1232 lb. of coal to build up the boiler pressure from an empty grate to full operation. The side dump stoker can be handled more easily than the multiple retort type and adapts itself to a wider range of conditions. Adjustment of the coal distributing mechanism is not difficult and hence a wide variety of coals may be burned satisfactorily. Fuel may be fed to the hopper from an overhead bunker, or where necessary by hand from a floor level coal pile.

Where high ratings are to be maintained over long periods, the multiple retort stoker will best serve the purpose, but the latest designs of multiple retort stokers emphasize large capacity and the complete burning of the fuel with simple ash disposal, rather than adaptability to smaller size units. The side dump stoker cannot compete with the large capacity, multiple retort stoker in the larger sizes, but in the range under discussion it is preeminent. It is built in widths up to 150 in. and depths of 110 in., or a maximum grate area of 114 sq. ft., sufficient for a 600 hp. boiler. At 200 per cent of rating this would be 37 lb. of coal per sq. ft. per hour. With Pittsburgh coal containing 30 to 38 per cent volatile, 3 to 10 per cent ash, and 13,000 to 14,000 B.t.u. per lb., it is possible to maintain combustion rates of 45 to 55 lb. per sq. ft. of grate area per hr. Large combustion space must be provided for these high volatile coals.

For the low volatile coals of 16 to 22 per cent volatile and 13,000 to 15,000 B.t.u. per lb. it is necessary that the fuel bed be uniform and porous to allow for air passage through the bed and agitation is therefore absolutely essential. The combustion space need not be as large as for the high volatile, low ash coals. The center retort stoker with its comparatively flat grates meets the fuel bed requirements.

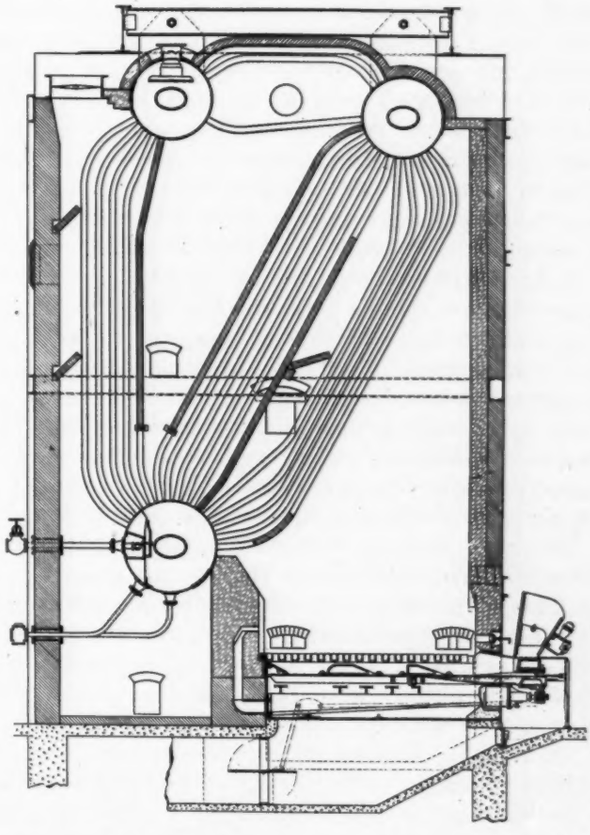


Fig. 4—Modern small plant unit consisting of a bent tube boiler fired by a center-retort underfeed stoker.

For the burning of slack or run-of-mine coal under small-size, natural draft boilers one of the several

so-called "hand" stokers may be used. These stokers are of the overfeed type with various schemes for breaking up the fuel bed and progressively feeding the coal towards the dump. They are sometimes furnished with a fan, coal hopper and mechanical feeder, but in most cases are hand fed. The free burning coals can, without difficulty, be burned on this class of stoker since agitation is not required, but the combustion rates should not exceed 30 lb. per hr. continuously and 35 to 40 lb. for short periods. Small boilers present the best field for this class of stoker, but they have been built to serve boilers as large as 400 hp. These hand stokers fill a certain restricted field where low first cost is of prime importance and the fuel especially suitable, but in spite of many arguments for their use they are only a palliative, filling a position between hand-firing and stoker operation.

Chain grate stokers will handle most Pittsburgh coals satisfactorily but are not so well suited to coals which have a tendency to coke and swell. When chain grates are used for this fuel they should be of extra length in order to burn out the carbon in the ash. The fuel bed should not be more than 5 or 6 in. thick, and above all sufficient grate area must be provided to insure lower combustion rates than with underfeed stokers. As we travel westward into the region of the free burning, high ash, low B.t.u. coals we find the chain grate stoker more prominent and the underfeed less so. Arch construction should be designed to fit the coal and this is particularly true with the low grade fuels. Continuous ignition and the combustion of the fixed carbon depend greatly upon the design of arch. The forced blast chain grate with proper design of furnace can be used successfully with these coals and ratings maintained much in excess of those possible with its predecessor, the natural draft chain grate stoker.

The high volatile bituminous fuels require for their efficient burning large combustion space since combustion is not so complete in the fuel bed itself. The size is also governed by the nature of the coal and the desired combustion rate. The tendency of the coal to clinker must be taken into account in determining the type of wall at the clinker line. With the size boilers under consideration, water walls are rarely justified. Where overfeed stokers or traveling grates are used, the shape of the arch is important so as to maintain combustion, especially in the initial stages. One of the chief items in the maintenance of the boiler is that of furnace brick work and it depends greatly upon the furnace design, grade of fuel and rate of firing.

Hand-firing may safely be said to be in its last stages. It is questionable whether it will survive even in the smallest plants. In the field of the small h.r.t. boilers, up to 150 hp., special types of stokers have been developed and are rapidly gaining ground. Even where but one or two small boilers are in service it may be found economical to consider automatic stokers. It is true that it does not reduce the labor cost, for one fireman is still required, but in many instances he can devote some of his time to other work. City smoke ordinances are becoming stricter and it will not be long before some form of stoker will be insisted upon. It is sometimes difficult to show an actual monetary saving on the investment but it may be justified by such intangible factors as smoke reduction without steam jets or other preventives, reduction of boiler strains, cleaner boiler room and increased morale of the fireman. The old line fireman who was content to hand fire one or two small boilers and consider it a worth while job is disappearing. A factor which must not be overlooked is the growing scarcity of the capable hand fireman. He is rapidly giving way to the newer type of man who is not merely interested in

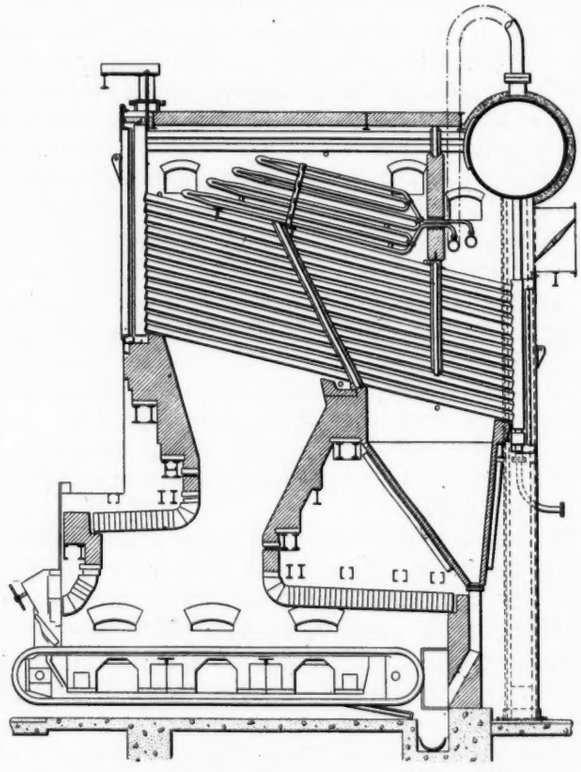


Fig. 5—Cross-drum sectional header boiler fired by chain grate stoker. This unit with its long rear arch evidences the modern trend in chain grate furnace design.

throwing coal into the furnace and wheeling ashes to the dump. If he is ambitious he wants something of a higher order, and he can usually make a stoker pay for itself.

Automatic stokers, suitable for the comparatively small heating boilers, also have been developed and found satisfactory. The advent of this small stoker has brought in a large number of variously designed mechanisms, in most of which the coal is pushed forward by means of a screw. The operation parallels that of the underfeed stoker and air is sup-

plied under pressure by a small forced draft fan to a series of tuyeres in the upper portion of the retort. Combustion takes place on dead plates which surround this central retort. The ability of the stoker to function properly depends to an extent upon the ash forming a clinker on the dead plates from which it is removed manually, since most of these stokers employ no dumping mechanism. The forced draft produces a hot, smokeless fire but in the small boiler, particularly the so-called heating boilers, small furnaces with low settings predominate and it is therefore very important that the furnace refractory be of high quality so as to prevent deterioration of the furnace walls and permit the removal of the clinker. These stokers are proving valuable in many instances and are an important factor in the more economical burning of coal and in smoke prevention. However, many of them show on the part of the designer a greater knowledge of mechanics than of boilers or combustion and extreme care must be taken that the stoker will do the work claimed for it.

There are isolated instances where hand-firing is justified and where nothing sufficiently important is to be gained by the installation of stokers. An example of this kind may be found in the case of the boiler plant using mostly shavings or refuse fuel, burned in suspension, and requiring but small quantities of coal at various intervals, or small plants where the quantity of steam required is comparatively low or consists simply of a heating load requiring operation only a part of the year. Such installations do not warrant more expensive equipment than a flat or shaking grate, but they are becoming more infrequent as time goes on.

Little has been said of pulverized fuel firing. This is not due to any thought of ignoring its value or its rapid adoption by many stations. In the early stages of its development, the large and costly central fuel preparation and grinding plant with distributors and feeders seemed the ideal method of firing large units. The cost involved naturally limited it only to the very large power stations. The advent of the unit pulverizer, however, has changed the complexion of things, materially, and not only is this type pulverizer built in sizes suitable for small boilers but it is finding rapidly increasing adoption in large stations where the central or storage system was formerly thought to be the only suitable method. Insofar as the capacity of these unit pulverizers is concerned they are readily adaptable to the boilers under consideration in this article, but in the average industrial plant there is practically no load at night or during the off periods and this does not fit in so well with the use of pulverized fuel. Where load conditions permit the adoption of this form of firing, there is no reason why it should not be given consideration, but extreme care should be taken to make certain that it better meets the requirements than would a properly selected stoker.

Frequently a boiler, still in fair condition, but incapable of supplying an increased steam demand with the old setting, can be raised and its steaming capacity thereby increased two or three fold by the installation of a unit pulverizer. The cost of the pulverizer installation is not greatly different from that of the stoker and it may in some cases be preferable. Under favorable conditions it probably will show a slight increase in economy. It has the advantage that the firemen can maintain efficient operating conditions with less ability than is required with a stoker. If the pulverizer is in good condition and the installation properly designed and suitable for the work, there is but little to do outside of seeing that these conditions are maintained. This is particularly the case with automatic control which has reached a high state of development in connection with pulverized fuel.

Operation with pulverized fuel does not require as intimate a knowledge of firing and furnace operation. The upkeep of the pulverizer must not be overlooked and it will likely be somewhat higher than the stoker. Where the load is fluctuating in character and frequently drops to comparatively low ratings for lengthy periods, a stoker will follow with less difficulty and the average economy will be better. Pulverized fuel generally permits higher ratings than a stoker and at these high ratings pulverized fuel firing can be adjusted more easily to meet changes in load than can the stoker with its deep fuel bed. If conditions demand an extremely high output for short periods this may be the determining factor in selecting pulverized fuel. The installation of a stoker under an existing hand-fired boiler is a comparatively simple job and usually does not involve as much engineering or construction work as a change-over to pulverized fuel which necessitates a much deeper or specially constructed furnace. In general, special conditions must obtain with the small plant to warrant the use of pulverized fuel but, where it does fit, it may be adopted with safety for it has long passed the experimental stage.

The unit pulverizer has reached a high state of development and a number of designs are on the market. In general, they belong either to the impact or hammer mill or to the tube or ball mill types. The former greatly predominates and seems to handle coal containing moisture with greater ease. There is a growing tendency to dispense with preliminary drying, preheated air being taken directly into the pulverizer. The use of preheated air is more adaptable to pulverized fuel than to the stoker where it probably increases the maintenance cost. There are many notable installations of all types of unit pulverizers in service indicating that they have reached the stage of practical design and differ principally in their minor details. The cost of pulverization will depend principally upon the moisture and ash content of the fuel and to lesser extent on the type of pulverizer.

The Chemical Nature of Coal

The Benzenoid Character of the Main Coal Substance

•

By

PROFESSOR WILLIAM A. BONE, F. R. S.

Imperial College of Science and Technology,

L O N D O N

This is the first of a short series of articles which Professor Bone will contribute discussing the results of recent research on the chemical constitution of coal. In this article he points out that the facts thus far established indicate that the coal substance, regardless of geological age or chemical maturity, has an essentially benzenoid structure; in other words its carbon is mainly present as fused or connected benzene rings. This conclusion suggests new theories as to the nature of the formation of coal. Professor Bone's next article will discuss recent investigations which have thrown new light upon the maturing of coals and the origin and character of their coking properties.

ALTHOUGH for more than two hundred years mankind has been using coal intensively and modern industrialism is largely based upon it, it is strange, but nevertheless true, that next to nothing is known about its chemical nature. Of course it has long been known, that it originated from vegetable debris far back in geological time, that it contains carbon, hydrogen, oxygen, nitrogen, sulphur, etc., as well as mineral matter, and that it produces carbon dioxide, steam, sulphur dioxide, nitrogen, plus an ash when completely burnt; but such facts reveal little concerning the chemical constitution of the coal substance, beyond that it is organic in origin and nature.

Up to fifty years ago, and perhaps even later, engineers and industrial chemists acquiesced in such ignorance, because they were content to throw coal into a furnace or retort and to await results without much regard for either the economy or morality of their procedure. They were satisfied to raise steam, make coke and gas, etc., from it anyhow. But in recent years their attitude has changed, and coal is now rapidly coming into its own as one of the great organic raw materials with which Nature has endowed mankind and which she has a right to require man to use with both intelligence and respect. Hence modern coal research and fuel technology are destined ere long to revolutionize both theory and practice in regard to it. In other words, the chemist is going to make his engineering brother "sit up" about it, in fact to "take off his hat" to it, and generally to teach him "coal manners" which now he sadly lacks.

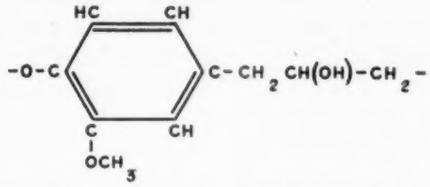
Any review of the chemical nature of coal must include all types and classes thereof from the least mature brown coals, through lignites and subbituminous right up to the most mature bituminous coals and anthracites. All of these should be regarded as representing some stage or product of the primary decomposition and subsequent transformation of vegetable debris into what may be termed "coal substance" of varying ages and maturities. The process has gone on since carboniferous times in all of the great geological epochs; and, so far as its earlier stages are concerned, it is being repeated in the peat bogs and swamps especially in northern latitudes where water-logged vegetable debris is decomposing under bacterial influences.

The original vegetable debris from which coal has been formed was composed chiefly of celluloses, lignin and proteins, together with smaller amounts of resinous bodies. It seems highly probable that during the peat-bog stage the celluloses and parts of the proteins were decomposed and resolved mainly into gases under bacterial influences, leaving the more resistant lignins, proteids and resins to be transformed later into "coal substance," *via* what are sometimes termed "humic" or "ulmic" bodies. From beginning to end the transformation process may be roughly pictured as involving (1) fermentations in peat bogs, with loss of the simpler celluloses and proteins, and conversion of the more resistant lignins and proteins into humic bodies, (2) progressive consolidation and de-watering of the resultant mass by pressure, accompanied by some slow rise in temperature, as the incipient coal deposit was gradually blanketed under accumulating newer strata, (3) effects of subsequent earth movements producing laminated structures, with some rise in temperature and (4) what may be termed "bitumenization" under the influence of increasing pressure plus slowly-rising temperature. Such bitumenization seems to have involved, among other things, a loss of carbon dioxide and water, in roughly $CO_2 + 2H_2O$ proportions due to what organic chemists call intramolecular condensation, and what (for want of a more precise term) may be described as an amalgama-

tion of humic and protein bodies, resulting ultimately in the "coal substances" of a matured bituminous coal. And in course of these transformation and maturing processes, bodies are gradually formed which ultimately are responsible for the coking propensities of bituminous coals.

Such being an outline of the course and conditions of coal formation, we may next deal with what recent research has revealed concerning the chemical nature of the coal substance.

It is of interest here to note that, according to the latest German researches, lignin has an aromatic and benzenoid structure. Indeed, Freudenberg has expressed the opinion recently that probably what may be termed the lignin unit is,



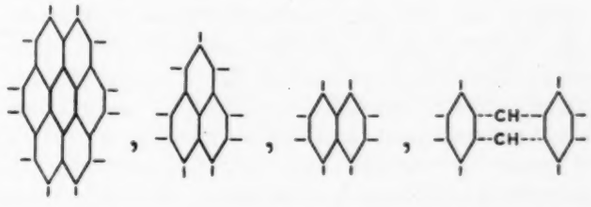
In investigating the chemical constitution of the coal substance considered as an organic product, it is best first of all to extract it with boiling benzene under pressure up to 700 lb. per sq. in. (temp. 280 deg. cent. or 536 deg. fahr.) in a "soxhlet" apparatus; whereby certain substances, including those ultimately causing the coking propensities of bituminous coals are removed as a crude extract which may amount to anything up to 15 per cent of the dry ashless coal substance, leaving a solid residue amounting to 85 per cent and upwards thereof. The various substances comprising the extract are of considerable interest particularly in connection with the swelling and coking properties of bituminous coals, and they will be fully dealt with in my next article. For the present, however, I propose to direct attention to the residue which is the main coal substance.

In the course of researches upon coals in all parts of the world, we have recently discovered that, no matter what the origin, geological age or maturing of a coal, the residue, after its benzene-pressure extraction, is readily oxidized and dissolved by a boiling solution of alkaline permanganate forming principally a mixture of benzene carboxylic acids, yielding anhydrides oxalic and acetic acids. Indeed, in some cases nearly 50 per cent of its carbon appears as benzene carboxylic acids, about 40 per cent of it as carbonic anhydride, about 7 per cent of it as oxalic acid and the remainder of it as acetic acid. Moreover, the benzene carboxylic acids so formed comprise no less than twelve out of the fourteen possible benzene carboxylic acids. All coals yet examined are alike in yielding such oxidation products. The weight yields are:—*benezene carboxylic acids*, between 25 and 50 per cent of the weight of the coal residue oxidized, *oxalic acid*, between 10 and 30 per cent, and *acetic acid circa*, 5 per cent. And in most cases the weight ratios benzenoid acids/oxalic acids is between 2.5 and 3.0.

It has also been proved that the first oxidation product is a colloidal humic acid, and that possibly complex crystalline acids of as yet unknown constitution, are formed intermediate between it and the benzenoid and other acids finally produced. There seem to be grounds for believing that probably the course of the oxidation is somewhat as follows: (Coal substance) to (Colloidal Humic Acid) to (possible unknown crystalline acids) to (Benzenoid, Oxalic and Acetic Acid) though further investigation (now proceeding) will be required for the complete elucidation of this aspect of the problem.

Seeing that there are many important questions, connected with the carbonization and hydrogenation of coal, which can only be fully understood and intelligently handled after its inmost chemical constitution is known, it will be seen that the foregoing discovery is of fundamental interest to both scientists and technologists and will probably lead to developments the world over, because everywhere chemists have long been searching for such a clue to the constitution of coal. But, important as this clue may be, we have still a long way to go before anything like finality in the matter can be reached; and there is plenty of room for the co-operation of chemists in all parts of the world in pushing the new discovery to its logical conclusion.

From the facts so far established, however, it may be concluded that the coal substance, no matter what its geological age or chemical maturity, has an essentially benzenoid structure; in other words, its carbon is mainly present as fused or connected benzene rings, such for example as:



All this suggests that, during geological time, the main coal substance may have arisen through condensation of phenolic and amino- (or imino-) with aldehydic bodies, much as 'bakelite' is synthesised nowadays, from phenols and formaldehydes.

Although, at first sight, this may seem a startling and somewhat revolutionary idea, on further thought it will be found to harmonize well with other known properties of coal. In the first place, it brings coal into line with the result of the most recent work upon the chemical constitution of lignin; next it would explain much of what is known concerning the 'hydrogenation' of coal, and finally it opens up great possibilities of converting coal commercially into useful organic compounds. Indeed, when such possibilities have been realized,

(*Continued on page 44*)

Blow-Down Losses and Their Correction

By A. R. MOBERG
Chemical Engineer, Elgin Softener Corp., Elgin, Il.

A previous article by Mr. Moberg, published in the December 1930 issue, dealt with the methods for calculation of blow-down losses. The present article discusses the reasons for such losses and means for their correction. The author explains the effects of surface tension, and concentration of solubles and suspended matter, and reaches the conclusion that the function of the blow-off valve is the reduction of concentration of soluble salts and that the reduction of concentration of suspended matter is incidental and is efficient only to a degree. From these facts, he arrives at the further conclusion that reduction in blow-down is dependent upon the efficient elimination of suspended matter and the reduction of soluble content of the feedwater. The article is concluded with a discussion of the conditions which existed in several actual cases and the steps taken for the correction of the losses involved.

BEFORE any methods for correction of blow-down losses can be considered, it is vital that we clarify the fundamental reasons for boiler blow-down. A great many operating engineers have long seemed of the opinion that boiler blow-down was for the primary purpose of eliminating mud from the boiler. When it is considered how a boiler is constructed it will be evident that such is not the purpose since no provision has been made to properly accumulate the mud in a boiler or to draw it off from several points, as for example in the case of the mud removal system of a lime-soda softener. A consideration of the chemistry and physics of the boiler water concentration will further emphasize the fact that boiler blow-down is not for the primary purpose of removing mud or loose scale from the boiler.

When water is evaporated from a boiler any salts that were in solution in that water or any mud or dirt that was present in that water are left behind. These salts constantly accumulate or concentrate as evaporation progresses and in time this concentrated water must be partially removed and replaced with water that is not so concentrated. This action obviously reduces the total concentration in the boiler by the dilution process and this dilution process is the function of the blow-off valve. Any reduction in blow-down losses must be based on an intimate knowledge of the chemistry and physics governing concentration.

There are two general classes of salts in a boiler water. One is known as a soluble salt because under normal circumstances it remains in solution in the water. The other class is known as insoluble because it leaves its soluble form and precipitates either as mud or as scale. Ordinary sediment or mud is classed as insoluble. This discussion does not deal with scale formation or prevention and so it will be presumed that some method will be used to change scale forming salts either to soluble salts or to mud forming salts. Since there is generally a choice of several such methods, however, the one to be chosen should be considered from the standpoint of its tendency to increase or decrease blow-down.

The soluble salts produce a change in the phenomenon known as surface tension. In other words, their presence tends to increase the resistance of the surface of the water to the passage of any other substance. Each soluble salt has its particular degree of surface tension and so the total surface tension of any water is dependent upon the amount and type of soluble salts existent in that water.

Now another fact must be given due consideration. Steam is formed at the point of contact between a heating surface and the body of water. Normally this heating surface is the boiler metal itself. The steam liberation through the surface of water is resisted to a certain extent by the surface tension of that water. When the pressure of the steam is sufficient it overcomes this resistance and escapes.

When steam is so liberated, the surface tension has a tendency to wrap a film around the steam "bubble" much the same as a soap bubble is formed. Since passage of steam is resisted by surface tension and since the release of steam through the surface tension tends to wrap the steam bubble in a film of water, it is evident that such action and conditions tend to carry moisture into the steam chamber or area. In other words, it becomes evident that surface tension is at least a contributory factor to the causation of foaming.

Mere surface tension is not the entire or even the primary cause of foaming since the surface tension of steam bubbles must be stabilized by finely divided suspended matter or from a soap produced by saponification of a grease or oil. Without the presence of some suspended matter or soap the stabilization of the bubble film is not usually suffi-

cient unless the surface tension is abnormally high. In other words, the steam bubble breaks and releases the water back to the boiler. On the other hand, no reasonable amount of suspended matter should influence foaming unless there is sufficient surface tension to be stabilized.

It will thus be evident that a reasonably high concentration of solubles and a correspondingly high surface tension may be carried in a boiler without grave danger of foaming providing suspended matter is virtually absent. It is inversely true that high concentration of suspended matter can be carried safely in the practical absence of surface tension. It must be remembered that a very slight increase in the concentration of suspended matter produces a large decrease in the allowable concentration of soluble matter or vice versa. The accompanying graph illustrates this feature. No definite figures are used in this illustration since actual amounts are dependent upon other circumstances, such as type of boilers and steam nozzles, rate of evaporation, etc.

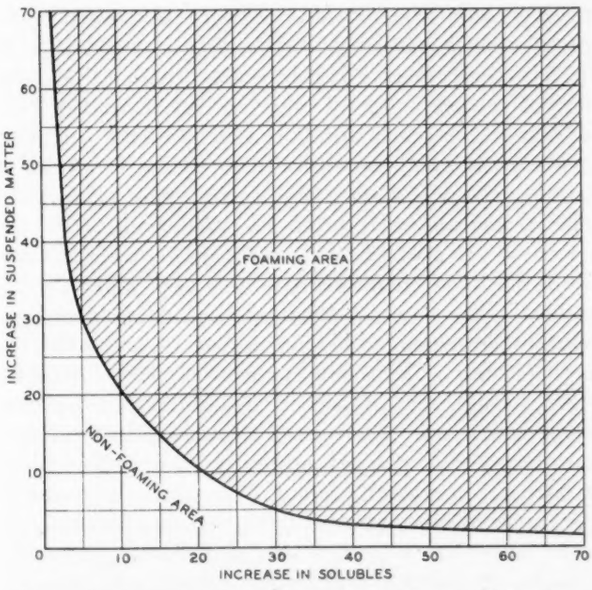


Chart showing effect of concentrations of suspended matter and solubles on foaming. Figures indicated are not actual but for comparison purposes only.

Another fact must now be given due consideration. Soluble salts by their very nature are evenly distributed throughout the whole volume of water. It is not so certain that suspended matter will be evenly distributed since its nature allows of stratification and sedimentation. If water were to be treated to precipitate suspended matter in the so-called mud drum, what would prevent its precipitation in other parts of the boiler? Sometimes coagulants are added to the boiler water, not to cause precipitation in the boiler but to produce a light flocculent mass that will remain in constant circulation and therefore be more evenly distributed throughout the volume of water. The important point is that if suspended matter is not evenly distributed throughout the entire volume, then the normal blow-down will not maintain standard ratios of soluble to suspended matter. This increases the amount of blow-down required as evaporation progresses since the allowable concentration of solubles is decreased by virtue of the increasing concentration of suspended matter.

It must become evident then that the function of the blow-off valve is the reduction of concentration of soluble salts and that the reduction of concentration of suspended matter is incidental and is efficient only to a degree. If we grant these facts it is self-evident that reduction in blow-down is dependent upon efficient elimination of suspended matter and reduction of soluble content of the boiler feed water.

In the light of the foregoing discussion it will be clear that the choice of boiler water conditioning equipment does not rest entirely upon the question of scale elimination. There are a great many ways to treat water to prevent scale and the degree of such prevention is usually dependent to a greater or lesser extent upon the care that is used in operating such equipment. The A.S.M.E. has recently suggested a code covering the relationship of certain salts that should be maintained in a boiler to prevent embrittlement of boiler metal. The economic maintenance of such relationship should be another consideration in the determination of proper conditioning equipment. Reduction or even utter elimination of blow-down should be a third but by no means least consideration in the choice of conditioning equipment. When we realize the great variety of waters and operating conditions to be found in this country, it becomes increasingly evident that no one type of equipment will be universally the most efficient in every case.

As an illustration, let us consider a water such as is found in the coal mining sections and particularly around Pittsburgh, Pennsylvania. Such a water will average about ten grains of hardness, of which about 90 per cent will be sulphate hardness and the balance will be bicarbonates. There will probably also be about one grain of sodium chloride in the water. Now if this water were softened by cold process lime and soda we could expect a residual hardness of between 2 and 3 grains per gal. There would probably be about the same amount of sodium alkalinity and of course the sodium chloride would remain the same while all of the sulphates would be converted to sodium sulphate. We would therefore have about 2.5 grains of potential mud-forming salts and about 13 grains of soluble salts. The sulphate carbonate ratio would be about 3.5 to 1.0, which would be sufficient to prevent embrittlement at pressures as high as 300 or 400 lb. At 150 per cent of rating with the average cross drum boiler, the allowable soluble concentration in the presence of 2.5 grains per gal. of suspended matter in the feed water would probably not exceed 150 grains. Even this would be predicated on the assumption that

efficient removal of suspended matter was obtainable. Such a concentration would account for a blow-down of approximately 9.5 per cent of steam production if the makeup were 100 per cent.

If the heat balance of this plant permitted the use of hot process lime-soda softening, the residual hardness might be reduced to about 1 or 1½ grains and the sodium alkalinity to a like figure. This would be better since the reduction in suspended matter would probably increase the allowable soluble concentration 25 or 50 grains and the rate of such concentration would be decreased about 8 per cent.

A still better procedure, however, would be the use of zeolite softening which would virtually eliminate the suspended solids and reduce the rate of soluble concentration to 11 grains. Such circumstances ought to allow a concentration of 250 grains in the boiler providing the load was reasonably steady and steam mains, etc., were properly designed. This would reduce the blow-down to about 4.6 per cent if the makeup were 100 per cent. It must also be noted that the sulphate carbonate ratio by this method would be increased to 9.0 to 1.0 thus allowing even higher pressure to be carried.

A continuous blow-down with heat exchange could be used to recover between 80 and 90 per cent of the heat units lost in this amount of blow-down. Determination as to whether or not such supplementary equipment would prove economically feasible would simply entail the balancing of interest and depreciation on the cost of such equipment against the value of the heat units so recovered. If the boilers were close to full capacity, it should also be considered that the heat units thus recovered could be applied in the production of additional steam.

Another illustration is the case of a large mercantile plant in the middle west. The water supply averaged about 18 grains of hardness of which 16.5 was bicarbonate hardness. There were about 2 grains of soluble salts. A zeolite softener had been installed some years previously which supplied the 75 per cent of makeup required. At from 150 to 200 per cent rating, only about 225 grains of solubles could be carried in the boiler without evidences of carry-over. The softening operation converted all of the hardness into soluble salts making a total of 20 grains per gal. The bicarbonates broke down under boiler pressure to form carbonates and hydroxides giving a sulphate-carbonate ratio of only .35 to 1.0 which was insufficient for the 175 lb. pressure at which the boilers were operated. In an attempt to correct this ratio, sodium sulphate was added bringing the total solubles up to about 24 grains per gal. This caused a blow-down schedule of 8 per cent. of the evaporation and then the sulphate-carbonate ratio had only been increased to .80 to 1.0.

Sodium phosphate might have been used for embrittlement prevention and 80 per cent of the heat units recovered by the continuous blow-down and heat exchange system. A comparison of the costs and economies to be effected, based on the formulas presented in the first article of this series (December 1930 issue), indicated materially in favor of sludge removal deconcentrators.

All that could be saved with the heat exchange would be about 80 per cent of the B.t.u.'s lost in blow-down. With the deconcentrator equipment about the same B.t.u. saving could be effected through reduced blow-down. In addition, 90 per cent of the softening cost would be saving; also the cost of the water and softening of the amount that would be blown down through continuous blow-down.

Under this system only about 10 per cent of the makeup water would have to be zeolite softened. The other 90 per cent could be by-passed around the softener. This immediately saved the cost of softening this 90 per cent which amounted to some 60,000 gal. per day. Water cost 10 cents per 1000 gal. and 4000 gal. of waste were required each time the softener was regenerated. Under this system the softener only required regeneration one tenth as often as previously. The bicarbonates in the 10 per cent of zeolite softened water broke down to form sodium carbonate in the boiler in sufficient quantity to react the calcium sulphate in the 90 per cent of hard water makeup and precipitate these salts as insoluble calcium carbonate. The calcium bicarbonate in the 90 per cent of hard water makeup also broke down to form insoluble calcium carbonate in the boiler. The sludge removal deconcentrators removed the suspended matter as fast as it was formed in the boilers. The same concentration of solubles could still be maintained in the boiler but the rate of concentration was reduced from 24 grains per gal. to only 4 grains per gal. showing a blow-down loss of only 1.25 per cent. Since this was the amount of loss in the sludge removal from the deconcentrators, boiler blow-down as such was eliminated. Since the amount of sodium alkalinity introduced into the boiler was just in excess of the amount required for precipitation of the calcium sulphate, the sulphate carbonate ratio was automatically corrected by reducing the carbonates instead of increasing the sulphates.

This system not only reduced the heat unit loss through the blow-down but saved the cost of water and treatment for this amount of water and in addition saved 90 per cent of the softener operation cost. Had this plant been buying a new softener it could have installed one of one tenth the size that had been purchased to soften all the water used for makeup.

Another example is a city owned Light and Power plant in the middle west. Jet condensers and a spray pond are used and so the boiler feed is 100 per cent of the spray pond water. Spray pond make-up is

(Continued on page 44)

Thermal Properties of Gaseous Mixtures*

By WM. L. DEBAUFRE
International Combustion Engineering Corporation
New York

In this discussion of the thermal properties of gaseous mixtures, the author describes the principles involved in gas analyses as exemplified by the Orsat method, and shows how to determine the various properties of gaseous mixtures such as density, specific heat, etc. The relationships between these properties and the effects of pressure and temperature thereon are also discussed. These relations are involved in combustion calculations which the author will discuss in a later article.

•

IN preceding articles, the thermal properties of gases have been discussed for gases considered as simple substances, such as steam, nitrogen, oxygen, etc. When atmospheric air was under discussion, no mention was made of the dependence of its thermal properties upon its composition, except to specify dry air. This method of treating the thermal properties of gaseous mixtures is satisfactory in many practical problems. There are certain industrial processes, however, which involve changes of thermal properties with changes in composition of the gases concerned. The process of combustion is the outstanding example.

Thermal changes during combustion will be treated in an article to follow. The present article will deal with the general relations between the thermal properties and the composition of mixtures of gases.

Atmospheric Air

The non-elemental character of atmospheric air was first discovered in Europe towards the end of the 15th century by Leonardo da Vinci who found that only part is consumed in combustion and respiration. Lavoiser later named the active portion "oxygen" from Greek words meaning "to form acids" because he regarded this element as an essential constituent of all acids. Certain acids have since been found that do not contain oxygen, but the name has been retained. Lavoiser named the inactive portion "azote" from its inability to support life. This name is still used in French for nitrogen, the English name selected by Chaftel because this element is an essential constituent of "nitre." Up to nearly the end of the 20th century, atmospheric air was supposed to be composed of oxygen and nitrogen with small amounts of water vapor and traces of carbon dioxide and hydrogen only.

The observation by Lord Rayleigh in 1892 that nitrogen obtained by separating oxygen from atmospheric air has a density about one-half of one per cent greater than nitrogen prepared chemically from ammonia and other nitrogen compounds, led Lord Rayleigh and Sir William Ramsay to the discovery in 1894 of argon, so named on account of its chemical inertness. Four other rare gases were soon thereafter discovered by Ramsay in atmospheric air, namely, helium, krypton, xenon and neon. Helium had previously been discovered in 1867 in the sun's chromosphere by means of a spectroscope used then for the first time during an eclipse. This element had been named helium from the Greek word "helios" for the sun. Krypton was found as an impurity of argon suspected because the atomic weight of argon did not fit into the periodic table of chemical elements. Its name means the hidden gas. It is twice as heavy as argon. Neon, the new gas, was found by further examination of argon. It is one-half as heavy as argon. Xenon, meaning the stranger, is over three times as dense as argon, and was first discovered by means of its spectrum as a component of a mixture of argon and krypton.

The composition of dry atmospheric air is given in the International Critical Tables as:

Nitrogen	78.03	per cent by volume
Oxygen	20.99	per cent by volume
Argon	0.94	per cent by volume
Carbon dioxide	0.03	per cent by volume
Hydrogen	0.01	per cent by volume
Neon	0.00123	per cent by volume
Helium	0.0004	per cent by volume
Krypton	0.00005	per cent by volume
Xenon	0.000006	per cent by volume

The above composition of the dry gases of the atmosphere is remarkably constant over the earth's surface at ordinary elevations. At great elevations, the proportions of the components change from those given. This is of importance to the meteorologist but rarely to the engineer whose operations are usually confined to the surface of the earth. There is, however, a variable component of the atmosphere at the earth's surface which is of importance to the engineer. This variable is the proportion of water vapor. The humidity of atmospheric air and other gases will be discussed in the next article.

Gas Analysis

The commonly used method of analyzing gases will now be described with the object of showing that this method gives the volumetric composition of a gaseous mixture on the dry basis as usually tabulated and as illustrated above for atmospheric air. The

*All rights reserved by the author

analysis of atmospheric air, however, is a special operation if the proportions of the rarer elements are to be determined, not only by reason of the small quantities of these elements present but also because they are all chemically inert. The analysis of stack

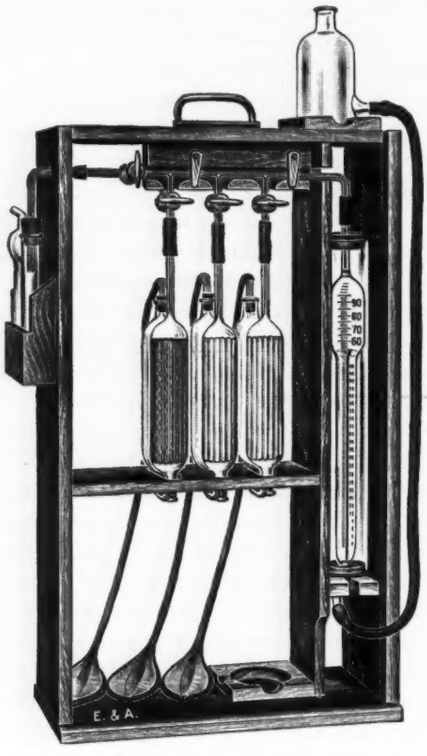


Fig. 1—Orsat gas analysis apparatus.

gases from a steam boiler will therefore be taken as an example of the commonly used method of gas analysis. The Orsat form of apparatus shown in Fig. 1 is usually employed.

A sample of the stack gases to be analyzed is first drawn into the measuring burette on the right. This gas sample is saturated with water vapor at atmospheric temperature due to the quantity of water vapor present before cooling the gaseous mixture from the stack temperature to the room temperature. If the gas were not saturated with water vapor, it would become so from contact with the water over which the gas is trapped in the measuring burette. The saturated water vapor present exerts a pressure corresponding to its temperature as given in tables of the properties of saturated steam. The dry gases present exert a pressure equal to that of the atmosphere minus the water vapor pressure. This is in accordance with Dalton's law enunciated in 1807 and later proven experimentally by Regnault that each constituent of a gaseous mixture exerts the same pressure it would exert if it alone were present in the volume occupied by the mixture. The total pressure exerted by the mixture is equal to the sum of the "partial pressures" exerted by all constituents.

After noting the volume in the measuring burette of the gaseous mixture under atmospheric pressure, the mixture is passed over into the first absorption pipette containing potassium hydroxide solution to absorb carbon dioxide. During the absorption of this constituent, the partial pressures exerted by the remaining constituents must increase in order that the total pressure of the mixture remain equal to atmospheric pressure. The partial pressure of the water vapor cannot increase, however, because it already has the maximum possible value at the temperature of the mixture. Therefore, as carbon dioxide is absorbed, the partial pressure of the water vapor remains constant but the partial pressures of the remaining dry constituents, oxygen, carbon monoxide and nitrogen, increase with corresponding decreases in their volumes. The water vapor partly condenses under constant pressure. Therefore, when the gaseous mixture is returned to the measuring burette, its volume is that of the remaining dry constituents compressed to a pressure less than atmospheric pressure by the saturated steam pressure corresponding to the temperature of the mixture. With no change in atmospheric pressure or temperature, the total pressure of the dry constituents after the removal of carbon dioxide will be the same as the total pressure of the dry constituents before the removal of carbon dioxide.

The above facts are diagrammatically represented in Fig. 2. The vertical distance AQ = ER represents the atmospheric pressure of 29.92 inches of mercury. The horizontal distance AE = QR represents the original volume, 100 cc., of the mixture in the measuring burette. The partial pressure of the water vapor initially is represented by LQ equal to 0.74 inch of mercury, the saturated steam pressure corresponding to 70 fahr. room temperature. The initial partial pressures of the dry constituents, nitrogen, carbon monoxide, oxygen and carbon dioxide, are represented by AF, FH, HJ and JL respectively. The initial total dry gas pressure is 29.92 — 0.74 = 29.18 inches of mercury.

When the carbon dioxide is removed in the first absorption pipette, the volume of the gaseous mixture decreases from AE to BE. The partial pressure of the water vapor remains constant and equal to LQ. The partial pressures of the remaining dry constituents increase from AF to BS, from FH to ST and from HJ to TM for nitrogen, carbon monoxide and oxygen respectively. By applying Boyle's law, it may be shown that the decrease AB in volume of the mixture is equal to that of the carbon dioxide originally present but compressed to the total pressure of the dry constituents.

After noting the percentage of carbon dioxide originally present in the gaseous mixture by observing the decreased volume in the measuring burette, the gas sample is passed over into the second absorption pipette containing an alkaline solution of pyrogallic acid for absorbing oxygen. During the removal of oxygen, a further condensation of water

vapor takes place and the carbon monoxide and nitrogen present are compressed to the total dry gas pressure of 29.18 inches of mercury. On the diagram, Fig. 2, the partial pressure of the nitrogen increases from BS to CU and that of the carbon monoxide from ST to UN. The distance BC corresponds to the volume of the oxygen initially present compressed to the total dry gas pressure.

A similar change occurs when the remaining gas is passed into the third pipette containing a hydrochloric acid solution of cuprous chloride for absorbing carbon monoxide. The partial pressure of the nitrogen increases from CU to DO in Fig. 2. The volume of the carbon monoxide removed is represented by CD and the volume of the nitrogen remaining is represented by DE.

It is thus evident that this method of analysis gives the percentage by volume of the dry constituents and does not measure the quantity of water vapor present. The water vapor present in stack gases is usually calculated from the quantities of moisture and hydrogen in the fuel burned and the relative humidity of the air supplied for combustion. The water vapor present could be determined experimentally by passing a measured volume of the gas over a drying agent and finding its increase in weight, or one of the methods to be explained in the next article for determining the humidity of atmospheric air might be employed.

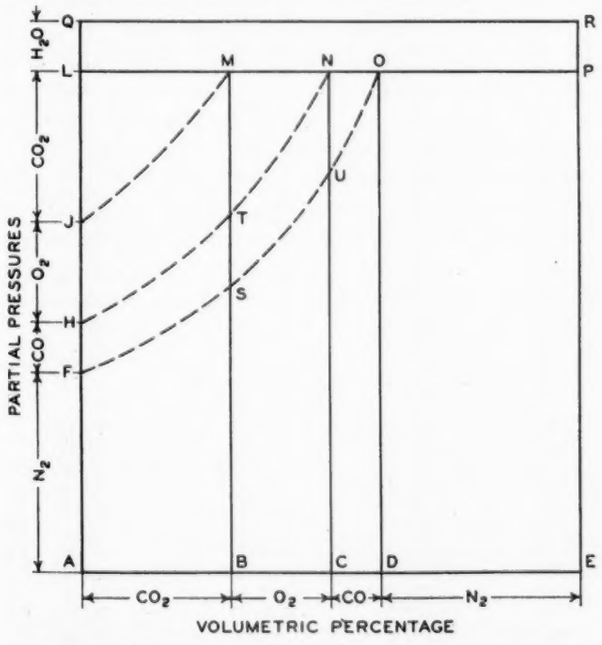


Fig. 2—Changes in volumes and partial pressures during gas analysis.

Composition of Gases by Weight

The composition of gases by weight is often desired instead of the composition by volume as given by the usual method of gas analysis just explained. The composition by weight can readily be calculated from the composition by volume. Thus, if the volumetric percentage of any constituent be multiplied by its density, the product is the weight of that constituent in one cubic foot of the gaseous mixture. The weight percentage of that constituent is found by dividing its weight by the sum of the weights of all constituents, which sum is the density of the mixture. The conversion from volume to weight percentage is shown below for a certain stack gas mixture. The densities used correspond to 32 fahr. and one atmosphere pressure.

Constituents	Per cent by volume	Density, lb./cu. ft.		Weight in one cu. ft., lb.	Per cent by weight
CO_2	14.0	× 0.12342	=	0.01728	20.3
O_2	5.1	× 0.08921	=	0.00455	5.4
CO	0.2	× 0.07806	=	0.00016	0.2
N_2	80.7	× 0.07807	=	0.06300	74.1
Density of mixture, lb. per cu. ft,				0.08499	100.0

If the density of any constituent is unknown, it may be found by dividing the molecular weight of the constituent by the volume of one mole, 359.0 cu. ft. at 32 fahr. and under one atmosphere pressure. The accuracy of such a calculation is indicated by the data in Table I where the calculated densities of a number of gases are given in comparison with observed experimental values taken from the International Critical Tables. The molecular weights are based on the following atomic weights: Hydrogen, 1.0077; nitrogen, 14.008; sulphur, 32.065. Slightly smaller densities would be calculated by using: Hydrogen, 1; nitrogen, 14; sulphur, 32.

TABLE I: DENSITY OF GASES

Gas	Formula	Molecular weight	Observed density gm. per liter	Observed density lb. per cu. ft.	Calculated density lb. per cu. ft.
Argon	A	39.91	1.7832	0.11132	0.11117
Helium	He	4.00	0.1785	0.01114	0.01114
Krypton	Kr	82.9	3.708	0.23149	0.23092
Neon	Ne	20.2	0.9002	0.05620	0.05627
Xenon	X	130.2	5.851	0.36528	0.36267
Hydrogen	H_2	2.0154	0.08988	0.00561	0.00561
Nitrogen	N_2	28.016	1.25057	0.07807	0.07804
Oxygen	O_2	32.000	1.42904	0.08921	0.08914
Carbon monoxide	CO	28.000	1.2504	0.07806	0.07799
Carbon dioxide	CO_2	44.000	1.9769	0.12342	0.12256
Sulphur dioxide	SO_2	64.065	2.9269	0.18273	0.17845
Hydrogen sulphide	H_2S	34.080	1.539	0.09608	0.09493
Ammonia	NH_3	17.031	0.7710	0.04813	0.04744
Methane	CH_4	16.031	0.7168	0.04475	0.04465
Acetylene	C_2H_2	26.015	1.173	0.07323	0.07247
Ethylene	C_2H_4	28.031	1.2604	0.07869	0.07808
Ethane	C_2H_6	30.046	1.3566	0.08469	0.08369
Propane	C_3H_8	44.062	2.020	0.12611	0.12274
Butane	C_4H_{10}	58.077	2.673	0.16687	0.16177
Dry air	0.7803 N_2, 0.2099 O_2, 0.0094 A, 0.0003 CO_2, 0.0001 H_2	28.966	1.2929	0.08072	0.08069
Atmospheric nitrogen	0.9876 N_2, 0.0119 A, 0.0004 CO_2, 0.0001 H_2	28.162	1.2568	0.07846	0.07845

Instead of using experimental or calculated densities of the constituents, the weight percentage of a gaseous mixture can be calculated from its volumetric composition by utilizing directly the molecular weights of the constituents. Thus, if the volumetric fraction of each constituent be multiplied by its

molecular weight, the product is the weight of that constituent in a volume of the mixture equal to one mole at the existing temperature and total pressure. Dividing each product by the sum of all products gives the weight composition of the mixture. The sum of the products for all constituents may be called the equivalent molecular weight of the mixture. Dividing the equivalent molecular weight by 359.0 cu. ft. gives the density of the gaseous mixture at 32 fahr. and under normal atmospheric pressure.

Applying this method to the volumetric composition of atmospheric air previously given, we have

Constituent	Per cent by volume		Molecular weight, lb.		Weight of one mole, lb.	Per cent by weight
N_2	78.03	×	28.016	=	21.861	75.47
O_2	20.99	×	32.000	=	6.717	23.19
A	0.94	×	39.91	=	0.375	1.29
CO_2	0.03	×	44.000	=	0.013	0.05
H_2	0.01	×	2.0154	=	0.000	0.00
Equivalent molecular weight of dry air,					28.966	100.00

Dividing 28.966 by 359.0, we get the density of dry atmospheric air to be 0.08069 lb. per cu. ft. at 32 fahr. under one atmosphere pressure.

If we assume atmospheric air to be composed of 21 per cent oxygen and 79 per cent nitrogen and to have the above equivalent molecular weight of 28.966 lb. per mole, it may be shown that "atmospheric nitrogen" would have a molecular weight of 28.16 lb. per mole instead of 28.02 lb. per mole for chemically pure nitrogen. Thus, the weight of the oxygen in one mole of the mixture would be 0.21 × 32.00 = 6.720 lb.; hence the weight of 0.79 mole of atmospheric nitrogen would be 28.966 — 6.720 = 22.246 lb. and its molecular weight would be 22.246 /0.79 = 28.16 lb. per mole. Weight calculations involving atmospheric air would be more nearly accurate if the molecular weight of atmospheric nitrogen were taken as 28.16 lb. per mole rather than using 28.02 or 28 lb. per mole which is correct for chemically pure nitrogen.

Density of a Gaseous Mixture at Any Temperature and Pressure

The density of a gaseous mixture at any other temperature than 32 fahr. can be found by dividing the equivalent molecular weight of the mixture by the volume of one mole at that temperature. To facilitate this calculation, the volumes of one mole at various temperatures under one atmosphere pressure, are given in Table II. The volumes of one mole at other than atmospheric pressure are found by dividing the tabulated values by the absolute pressure in atmospheres.

In Table II are also given the densities of dry atmospheric air at various temperatures under normal atmospheric pressure, calculated by dividing 28.966 by the volumes of one mole at the corresponding temperatures. The densities at any other than normal atmospheric pressure, are found by multiplying the tabulated values by the absolute pressure in atmospheres.

The specific volumes of dry atmospheric air given in Table II for normal atmospheric pressure are the reciprocals of the densities at corresponding temperatures.

It may be noted that the product of the density of dry atmospheric air in pounds per cubic foot and its absolute temperature in degrees fahrenheit, is equal to 39.67. Hence, the density of atmospheric air under normal atmospheric pressure at any temperature may be found approximately by dividing 40 by the absolute temperature. The specific volume of atmospheric air is approximately equal to the absolute temperature divided by 40.

Specific Heat of a Gaseous Mixture

So long as no liquefaction of any constituent occurs, thermal changes in heating and cooling and in expanding and compressing a gaseous mixture may be treated as if the mixture were a simple substance.

TABLE 11. GAS AND AIR DATA FOR NORMAL ATMOSPHERIC PRESSURE, 29.92 INCHES MERCURY.

Temperature, fahr.	Volume of one lb.-mole, cu. ft.	Density of dry atmospheric air, lb. per cu. ft.	Specific volume of dry atmospheric air, cu. ft. per lb.
0	335.6	0.08630	11.59
10	342.9	0.08447	11.84
20	350.2	0.08270	12.09
30	357.5	0.08102	12.34
32	359.0	0.08069	12.39
40	364.8	0.07939	12.59
50	372.1	0.07784	12.85
60	379.4	0.07634	13.10
70	386.8	0.07490	13.35
80	394.1	0.07351	13.61
90	401.4	0.07217	13.86
100	408.7	0.07088	14.11
200	481.7	0.06013	16.63
300	554.7	0.05222	19.15
400	627.7	0.04614	21.67
500	700.8	0.04133	24.19
600	773.8	0.03743	26.71
700	846.8	0.03421	29.23
800	919.8	0.03149	31.75
900	992.9	0.02917	34.28
1000	1065.9	0.02718	36.80
1100	1138.9	0.02543	39.32
1200	1212.0	0.02390	41.84
1300	1285.0	0.02254	44.36
1400	1358.0	0.02133	46.88
1500	1431.0	0.02024	49.40
1600	1504.1	0.01926	51.93
1700	1577.1	0.01837	54.45
1800	1650.1	0.01755	56.97
1900	1723.1	0.01681	59.49
2000	1796.2	0.01613	62.01
2100	1869.2	0.01550	64.53
2200	1942.2	0.01491	67.05
2300	2015.3	0.01437	69.57
2400	2088.3	0.01387	72.09
2500	2161.3	0.01340	74.62
2600	2234.3	0.01296	77.14
2700	2307.4	0.01255	79.66
2800	2380.4	0.01217	82.18
2900	2453.4	0.01181	84.70
3000	2526.4	0.01147	87.22

The specific heat of the mixture for use in such problems may be found by multiplying the specific heat of each constituent by the percentage of that constituent and adding the products. If volumetric percentages are used, the specific heats should be in B.t.u. per cu. ft. or preferably B.t.u. per mole. The ratio of the specific heats at constant pressure and constant volume is obtained by first calculating the specific

heats of the mixture at constant pressure and at constant volume and then dividing the former by the latter. The correct ratio for the mixture cannot be obtained directly from the ratios for the constituents.

For small temperature ranges and for moderate pressures, the perfect gas laws may be applied to isothermal and adiabatic changes of gaseous mixtures in the same manner as explained in previous articles for simple gases. For large temperature changes, the fact that the specific heats vary with temperature should be taken into account. Under very high pressures, other modifications in the calculations are necessary as previously explained for simple gases.

The specific heats will be calculated for the gaseous mixture below, utilizing the table of specific heats of simple gases given in the article on "The Thermal Properties of Gases." For a temperature of 1000 fahr., we have:

Constituent	Per Cent by volume	Specific heat, B.t.u. per lb. mole per deg. fahr.	Heat for constituent, B.t.u. per deg. fahr.
CO_2	13.2	11.62	1.534
H_2O	5.5	8.83	0.486
O_2, CO, N_2	81.3	7.19	5.845
Specific heat for mixture, B.t.u. per lb.-mole			7.865

The above specific heat is for heating under constant pressure. The specific heat at constant volume is found by subtracting 1.985 B.t.u. per lb.-mole per deg. fahr. from the specific heat under constant pressure, obtaining 7.865 — 1.985 = 5.880 B.t.u. per lb.-mole per degree fahr. The ratio of the specific heats is 7.865/5.880 = 1.34.

The heat added under constant pressure between any two given temperatures may be most conveniently found for a gaseous mixture by utilizing the table of sensible heats of simple gases given in the article entitled, "Thermal Changes in Gases." For a temperature change from 70 to 2000 fahr., we have for the above gas:

CO_2	0.132 × 613.3	=	81.0 B.t.u.
H_2O	0.055 × 580.8	=	31.9 B.t.u.
O_2, CO, N_2	0.813 × 487.2	=	396.1 B.t.u.
Sensible heat at 70 fahr.			509.0 B.t.u. per lb.-mole
CO_2	0.132 × 27,729.5	=	3000.3 B.t.u.
H_2O	0.055 × 17,938.7	=	9866.3 B.t.u.
O_2, CO, N_2	0.813 × 14,451.3	=	11748.9 B.t.u.
Sensible heat at 2000 fahr.			24615.5 B.t.u. per lb.-mole

Heat added under constant pressure = 24,615.5 — 509.0 = 24,106.5 B.t.u. per lb.-mole.

Entropy of Gaseous Mixtures

In a given volume of a gaseous mixture, each constituent has the same entropy as well as the same pressure, the same internal energy and the same total heat as it would have if the other constituents were not present. This is exactly true for "perfect gases" and approximately true for actual gases.

The significance of the above statement becomes apparent upon considering two vessels containing different gases which are permitted to diffuse through an opening between the two vessels until a homogenous mixture occupies both vessels. If the pressures in the two vessels are equal before diffusion starts, there will be no change in pressure during diffusion. Each gas will expand into the other vessel as if the other gas were not present. Thus, denoting by v_a the volume of the vessel containing gas A at pressure p and by v_b the volume of the vessel containing gas B at pressure p, we have by Boyle's law: Partial pressure of gas A after expansion, $p_a = p\,v_a/(v_a+v_b)$; and partial pressure of gas B after expansion, $p_b = p\,v_b/(v_a+v_b)$. Whence, $p_a + p_b = p$. Also, since the internal energy of a perfect gas does not vary with change in volume, the internal energy of the mixture after diffusion will equal the sum of the internal energies of the two gases before diffusion provided no heat enters or leaves the vessels during diffusion. The same equality evidently holds for the total heats before and after diffusion.

The entropy, however, of each constituent increases as it expands isothermally from one vessel to the volume of both vessels. Therefore, the entropy of the mixture which is equal to the sum of the entropies of the two gases after diffusion, is greater than the sum of the entropies of the two gases before diffusion. The process of diffusion produces an increase in entropy which may be calculated from the expression for the entropy of a perfect gas in the article on "The Thermal Properties of Gases," namely,

$$s = c_v \log_e T + A R \log_e v + s_o$$
$$= c_p \log_e T - A R \log_e p + s_o$$

Before diffusion, we have for gas A,

$$s'_a = c_p \log_e T - A R \log_e p + s_o$$

After diffusion, we have for constituent A,

$$s''_a = c_p \log_e T - A R \log_e p_a + s_o$$

The change in entropy for constituent A is

$$s''_a - s'_a = A R \log_e p/p_a$$

If there are present m_a moles of gas A and m_b moles of gas B, the total increase in entropy due to diffusion is

$$\Delta s = m_a A R \log_e p/p_a + m_b A R \log_e p/p_b.$$

This increase in entropy indicates an irreversible process with a corresponding decrease in the capability of doing work. A mixture of gases at a given pressure and temperature would at first sight appear capable of doing as much work as the constituents at the same pressure and temperature. This is not true, however, for with the proper appliance it would be possible to perform mechanical work during the mixing of gases. Such an appliance would comprise two pistons in a cylinder, each piston being permeable to one gas but impermeable to the other gas. Initially, the pistons would be together with the gases A and B on either side of them. Then they would be permitted to move apart, each piston doing

(Continued on page 44)

European Practice in Boiler Feed Pump Drives

The various types of boiler feed pumps used in Great Britain were described in an article by David Brownlie, published in October 1930, COMBUSTION. In the present article, Mr. Tupholme discusses European practice with reference to methods of driving centrifugal feed pumps and the factors which affect the selection of pump drives. The article is concluded with a report of test conducted on a turbine-driven pump, the condensate from which was used for heating the feedwater.

By C. H. S. TUPHOLME, London

FEW boiler plants of any size now employ reciprocating boiler feed pumps. The centrifugal pump has a number of advantages for this type of service which need not be enumerated here and engineers of both central and private generating stations have been quick to appreciate the advantages of this type over the older reciprocating pumps. At the present moment the much debated question is not which type of pump to install but how that pump shall be driven—electric or turbine?

Driving centrifugal pumps by turbine has the advantage of making the operation independent of any other source of power; but where electric current is cheaper than coal, as it is in some European countries, electric drive has certainly the advantage of being more economical, providing no further use can be found for the exhaust steam. If, on the other hand, the exhaust steam can be utilized for preheating the feedwater or for any other purpose, it will be found much cheaper to drive the pump by steam turbine, and this system is found far more economical even when the cost of electricity is low.

In deciding if it is better to utilize the exhaust steam for preheating the feedwater, it must not be thought that the efficiency of the economizer will thereby be to any extent impaired. Especially where cold feedwater is used, or where the condenser water is comparatively cold, as is usual today in steam turbine plants with surface condensation in consequence of the efforts made to obtain a high vacuum, the waste heat in the stack gases can be employed in the economizer as usual. Preheating is, on the contrary, to be recommended in such cases, in order to prevent sweating of the economizer tubes. When it is not possible to utilize the exhaust steam from the turbine, the centrifugal boiler feed pump may be driven by an electric motor. It is well, however, even then to install a turbine-driven boiler feed pump so as to have a certain reserve.

The turbines used for driving the pumps are simple impulse turbines with partial steam admission. They have only one wheel, with one pressure stage and two or three velocity stages. The blading of the runner and of the guide segments is made of bronze of a particular composition, which will withstand the temperatures of highly superheated steam.

In the wheel and guide segments are dovetailed recesses in which the blades are held by suitably shaped distance pieces, so that it is quite impossible for the blades to work loose, even when working with highly superheated steam. In consequence of the runner of the turbine being overhung, only one stuffing box is necessary. This is fitted with a special carbon packing in the form of rings which surround the shaft and are held together by springs. This form of packing is practically frictionless and requires no lubrication. The mainshaft runs in substantial water-cooled bearings.

The various types of turbines intended for driving boiler feed pumps are constructed for use with dry saturated steam or for steam superheated up to 750 deg. fahr. at pressures of 85 to 330 lb. per sq. in., and for back pressures up to 60 lb. per sq. in. In the smaller sizes the impeller of the pump is keyed directly on the main shaft of the turbine, and in the larger sizes, the turbine and pump are direct-connected by means of a flexible coupling.

Turbo boiler feed pumps have recently been required for delivering water to boilers against pressures of 400 to 600 lb. per sq. in. The turbine must often work with a back pressure of 40 to 60 lb. A turbine for these conditions is shown in Fig. 1. This is built for an initial pressure of about 500 lb. per sq. in. and works with a back pressure of about 55 lb. A packing of special design, consisting of carbon rings, is used for rendering the shaft tight, thereby reducing to a minimum the loss of steam along the shaft.

These turbo boiler feed pumps are governed by a hydraulic or diaphragm governor which is controlled by the delivery pressure of the pump and by the pressure in the boiler. In addition there is a safety governor actuating an automatic device which

shuts off the steam supply to the turbine as soon as its speed exceeds a certain figure.

The action of the hydraulic governor, shown in Fig. 2, is based on the principle that the difference between the pressure of the pump and the pressure of the boiler shall remain constant. Steam comes from the boiler through the stop valve A and the regulating valve B, which, according to the load on the turbine, is more or less open, expands into the space C, from where it passes through the piping D into the turbine. The regulating valve B is adjusted by the diaphragm E on which the piston F with the

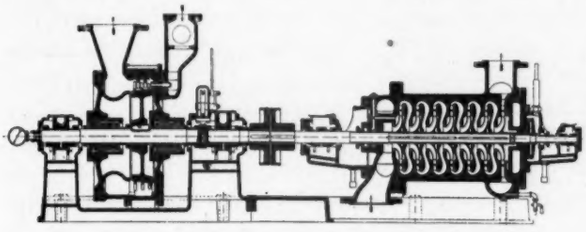


Fig. 1—Section through a turbo boiler feed pump for high pressures.

valve spindle G and the spring H rest. The tension of this spring can be regulated between certain limits by means of the worm and worm wheel J and K while the turbine is working.

A cooling jacket M, through which the cooling water from the bearings flows, prevents the diaphragm from becoming too warm. The space N under the diaphragm E is connected by the pipe O with the delivery branch of the feed pump, and the space P over the diaphragm is connected by the hole Q with the steam piping. As the effective pressure areas on both sides of the diaphragm are equally large, the pump pressure always remains higher than the boiler pressure by an amount equal to the pressure of the spring, and the pump is adjusted according to the size of the piping to develop a pressure of 20 to 70 lb. per sq. in. higher than the boiler.

Governing is effected by means of the diaphragm. If, for example, in consequence of a large quantity of water being required, the amount delivered by the pump is increased and the pressure in the space N thereby sinks, the diaphragm moves downward, and with it the spindle. The amount of opening of the throttle valve is therefore increased, and the speed of the set rises in consequence of the increased amount of steam admitted, thus causing the pump pressure to increase. On the other hand, when the amount delivered is decreased, the pressure in the space N rises, and the amount of steam admitted to the turbine is decreased.

The method of regulation described, which has been very widely adopted, has the advantage of giving a pump pressure which always suits the boiler pressure, and loss of energy is thus avoided.

A flyweight R, constructed as an eccentric ring, actuates the safety governor as soon as a predetermined speed is exceeded. The governor is adjusted to the speed desired by means of the spring S. The flyweight R actuates a series of rods, thus closing the valve A.

Under normal conditions the pumps are designed to develop a pressure of about 14 to 28 lb. per sq. in. higher than the maximum permissible steam pressure in the boiler. Where the piping is very long, it may be necessary to choose a pump developing a pressure more than 28 lb. per sq. in. higher than that of the boiler. The number of impellers in the pump depends on the pressure desired and the speed chosen, but, in order to have a reliable suction, there are never less than two. The small types in which the impellers are keyed directly on the turbine shaft have also two impellers.

When exhausting direct to the atmosphere, the back pressure at the outlet from the turbine is about 1½ to 3 lb. per sq. in. In this case the heat still contained in the exhaust can be utilized by passing the steam through heating coils fitted to the delivery piping from the pump, the condensate from the heating coils being led to the feedwater tank.

A much better method of utilizing the waste heat is to condense the exhaust steam by means of a jet

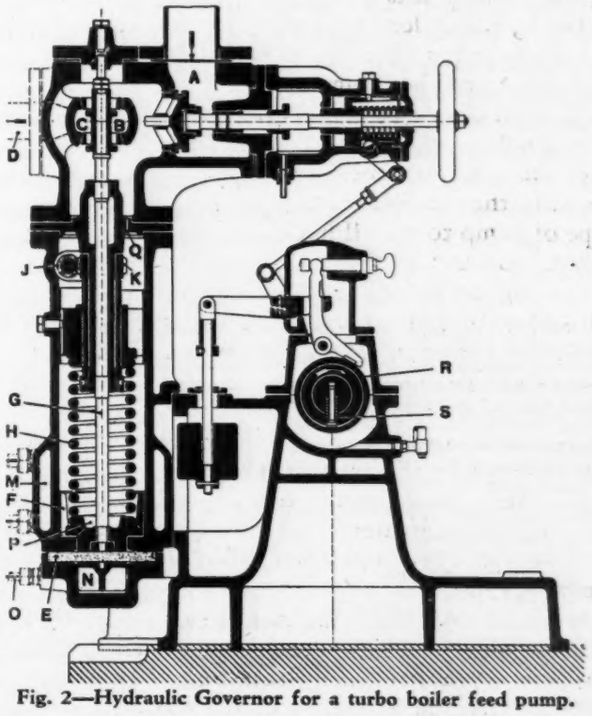


Fig. 2—Hydraulic Governor for a turbo boiler feed pump.

fitted in the feedwater tank. In this way the feedwater is heated up by the steam, and the waste heat in the steam is very largely recovered.

This simple method of condensation and utilization of the waste heat is not possible when reciprocating pumps are used for boiler feed, as the steam passed through them is contaminated by oil. The steam from the turbines, on the other hand, is free from any trace of oil, and the condensate can therefore be used again as boiler feedwater. Condensation of the exhaust steam in this manner is started by opening a

valve in the piping connecting the delivery branch of the pump with the jet in the feedwater tank. This valve is opened immediately after the turbo pump is started up, and is closed a few minutes after the pump has begun to develop its full pressure.

The admissible suction head decreases in proportion to the increase in the temperature of the feedwater, and it is therefore necessary, when the pumps have to deliver preheated water, to fit them at as low a level as possible, so that the water may flow to them under pressure. If it is absolutely impossible to do this, they must at least be installed at such a level that the suction head cannot exceed figures published by the manufacturers of the pumps. In accordance with such figures it is seen that the water must flow to the pump under pressure when the temperature is about 175 deg. fahr.

The extent to which it is possible to raise the temperature of the feedwater by condensation of exhaust steam from the turbine, and the economy thereby effected, is clearly demonstrated by the following recent test.

The Compagnie d'Electricite de l'Ouest-Parisien, of Puteaux, operates a Sulzer turbo boiler feed pump with an output of about 2750 gal. per min. against a pressure of around 310 lb. per sq. in. The pump requires approximately 110 b.h.p. to drive it, and runs at 4000 r.p.m. The turbine is supplied with steam at an admission pressure of 215 lb. per sq. in. and at a temperature of 570 deg. fahr., measured at the stop valve. This company recently carried out a series of endurance tests, with the following results:

Quantity of water fed to the boiler per hour	179,976 lb.
Manometric head	712 ft.
Absolute steam pressure in the boiler	230.8 lb. per sq. in.
Steam temperature at superheater outlet	457 deg. fahr.
Total heat of 1 lb. of steam	1235 B.t.u.
Steam consumption of turbine per hour	3580 lb.
Temperature of water in hotwell	106.5 deg. fahr.
Temperature of feedwater after mixing with exhaust steam	125 deg. fahr.

HEAT ACCOUNT PER WORKING HOUR

Heat supplied by boiler
3580 (1235 — 106.5 + 32) (685.4—41.4) .... 4,150,00 B.t.u.
of which is made useful
for feedwater $\frac{179,976 \times 712}{777.5}$ ... 164,800 B.t.u.
for heating the feedwater
179,976 (125 — 106.5) ..... 3,300,000 B.t.u.
The total heat utilized is therefore 3,464,800 B.t.u.
and the overall efficiency—
$\frac{3,464,800}{4,150,000}$ ..... 84 per cent.

Losses in the piping between the boiler and the turbine are allowed for in this figure. In the same power house is an electrically-driven Sulzer boiler feed pump for operating under the same conditions, and comparative tests carried out by the central station authorities mentioned showed a saving equivalent to about 90 tons of coal in 3000 hours by the turbine-driven pump over the electrically-driven one.

Novel Hydro Development In the Carolinas

DURING recent years there has been much discussion of various hydro-electric projects in the South. We welcome this opportunity of contributing a brief description of a unique installation which may have eluded the eyes of investigators and statisticians. North Carolina was credited with 650,000 kw. installed capacity at the close of 1930 but we hazard the guess that this figure does not include the installation shown in the accompanying illustration.

Hidden away in a sequestered spot on the bank of a little mountain stream in the Carolinas, this miniature power plant stands as a crude but successful effort to "get something for nothing."

An undershot water wheel is belted through a jack shaft to a generator which was salvaged from an abandoned Ford automobile. Two wires, one copper

Hillbilly hydro-electric plant in the Carolinas.

and one iron, span the intervening valley and carry the current to a series of low voltage lamps which are installed in the simple mountain cabin where lives the plant designer, builder, operator and the sole ultimate consumer.

Ingenuity and initiative are here combined with a working knowledge of elementary mechanics and the craftsmanship of some one who was handy with tools.

If "necessity is the mother of invention", this contrivance was sired by a nobler motive—the ambition of a resourceful man to raise his standard of living.

The bugaboo of hydro-electric development is the ever present item of high fixed charges which inevitably result from the tremendous capital costs involved.

This genius of the Carolinas has effectively avoided all fixed charges by the simple expedient of keeping his initial investment at zero.

Like its larger contemporaries, this hydro-electric installation has its fuel burning standby for emergency use. In this instance, the standby unit is a kerosene lamp.

Combined Burners for Firing Waste Fuels*

By
R. C. VROOM
Peabody Engineering Corporation
NEW YORK

Since the advent of pulverized fuel and oil firing on an extensive scale, much progress has been made in burner design. Today, so-called combined burners are available which are capable of firing pulverized, liquid and gaseous fuels simultaneously. Such burners are described in the accompanying article with particular reference to their adaptability in connection with waste fuels. . . . There has been an increased trend toward the utilization of fuels which are by-products of industrial processes. The petroleum industry is a particularly good example of this trend and has perhaps been more alert to take advantage of its residue fuels than have most other industries. The author describes typical installations of combined burners using various waste fuels from refineries. While this is not a complete version of the paper as presented before the A.S.M.E., only slight omissions have been made from the original text.

IN certain industrial processes, particularly in oil refineries, there are obtained various combustible by-products of residues which can be used as fuel providing suitable combustion equipment is employed. In the past, this utilization has been confined largely to those plants in which such materials were produced. In some cases, their combustion has proved so difficult that it has been impracticable to consume them in such a manner. As a result, they sometimes have collected in considerable quantities and their disposal has represented a serious problem.

Within recent years, waste fuels have become of increasing importance, and not only have more effective efforts been made to burn them in the plants where they are produced, but often they are given some treatment to minimize their undesirable characteristics. In this treated form, the better grades are being furnished to outside plants.

In some instances, public utility companies have found it economical to construct a steam station adjacent to an industrial plant in order to make use of its waste fuels. In such cases, the steam station supplies to the industrial plant process steam and electric current which the latter previously produced itself.

The combustion of residual or waste fuels requires special attention, as fuels which heretofore have not been considered commercial are now occupying a position of increasing importance.

In oil refineries, the use of such fuels has been coupled with the necessity for a great increase in heat liberation per furnace, per unit of furnace volume, and per burner, due to the fact that these fuels often must be used for firing large units requiring a high rate of heat absorption per unit of heating surface. Also, modern refining processes frequently are sensitive to furnace conditions and necessitate a greater use of radiant heat transfer with a minimum of excess air. In such cases, absolute control of flame shape and other furnace conditions is essential.

The use of a few flexible and economical high capacity burners for fuel firing, in contrast to a great number of smaller units, is in accordance with the modern trend of design for fuel firing and other plant equipment. Burners are available in sizes to liberate up to 100,000,000 B.t.u. per hr. when burning practically any liquid, gaseous or pulverized residual fuel, without any sacrifice in economy or flexibility, and with the ability to give absolute control over the furnace conditions.

Often such burners are used with highly preheated air. In oil still installations where there have been great advances in the methods employed, the use of preheated air has been developed beyond the range ordinarily found in power plants, temperatures approaching 1000 deg. fahr. sometimes being employed. Such temperatures, of course, require the use of insulated panel burner register fronts and special metals, not only for the register parts, but for air preheaters and other equipment in contact with the hot gases.

The higher air temperatures increase the forced draft pressure necessary at any given fuel rate per burner, and while the use of highly preheated air speeds combustion, the most careful burner design is required. Not only must air pressures be maintaine within reason, but at the same time the correct flame shape and the other desirable characteristics which the burner has when operating at lower temperatures must not be sacrificed. Maximum turbulence is essential, as each particle of fuel must come in intimate contact with the greater volume occupied by the air necessary to burn it.

Not only is it necessary to have individual burners

*Presented before the Metropolitan Section of the A. S. M. E., New York, January 20, 1931.

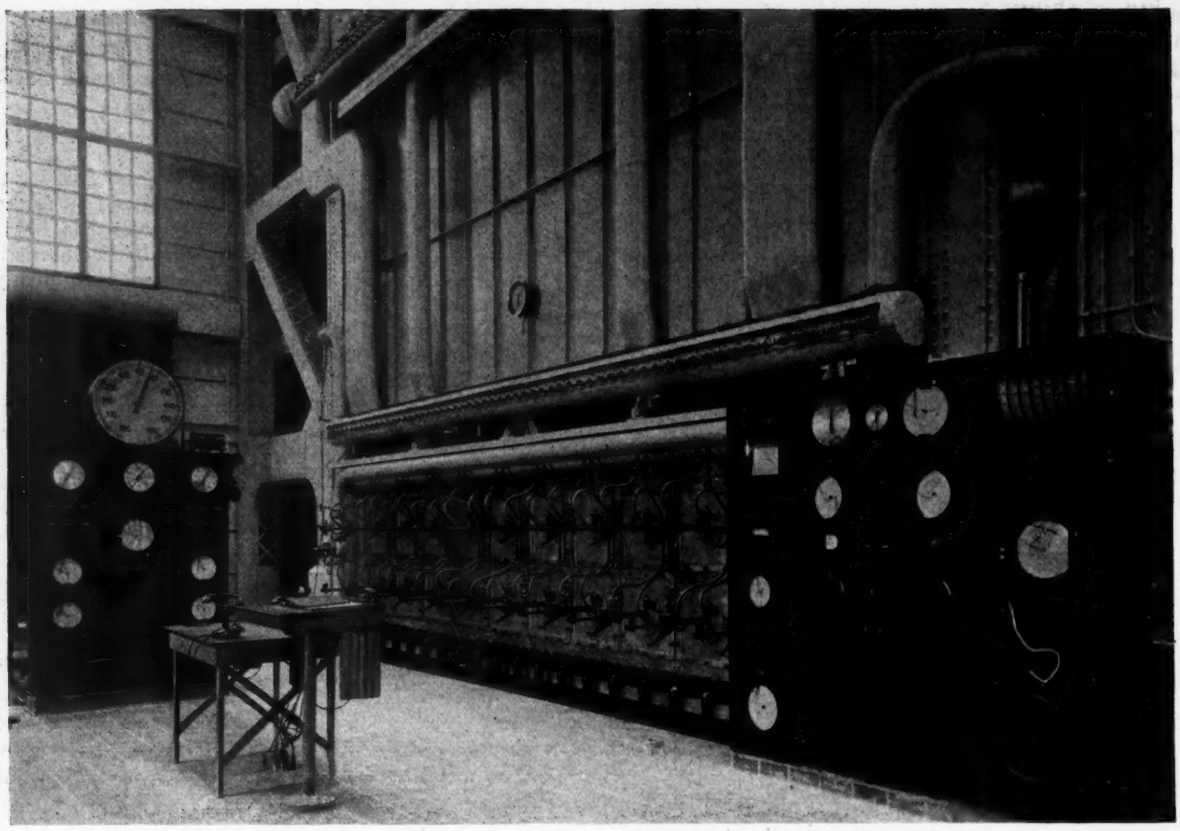


Fig. 1—Partial view of plant interior showing one of six 3400 hp. boilers each equipped with combined gas and oil burners.

which are capable of handling standard as well as waste fuels at high capacity, but it is essential to have flexible combined units for two or three fuels, these being capable of obtaining maximum capacity with any one of the fuels. Fig. 1 shows part of a boiler room having six 3400 hp. boilers, each equipped with 20 combined gas and oil burners.

The word "combined" as used in this connection must be taken in its proper sense, or else the full advantage of a combined burner will not be indicated. Until a few years ago, combined burners generally meant a multiplicity of burners for liquid, gaseous or pulverized fuels "combined" in the same furnace. What is meant in this paper by a "combined burner" is a burner in which any one of three forms of fuel—liquid, gaseous or pulverized—may be fired through the same throat opening into the furnace, and in which use is made of a common passage for the combustion air.

Combined units are advantageous for various reasons. In certain plants, they are needed due to the fact that prices of the different types of standard fuels may fluctuate widely from time to time and the use of such equipment enables the plant to burn that fuel which is the most economical. In some industries, there are obtained from the various processes numerous waste fuels which are of such a character as to have practically no market value, but the supply of such fuels is irregular or inadequate to carry the entire plant load continuously with the result that provision also must be made for burning standard fuels.

The advantages of combined burners over independent burners for the various types of fuels are numerous. These may be summarized as follows:

1. The ease of operation due to a fewer number of burners.
2. The simplicity of furnace and air duct construction and air control, due to the location of all burners in a single group in a common windbox, so that all fuels are fired through one furnace wall and with one set of throat openings into the furnace. The latter is of particular importance when water walls are used.
3. The ability to keep in operation at all times all of the burners firing any one furnace, thus eliminating the necessity for protecting the burners not in service.
4. The ability to light one fuel quickly from the other, permitting a practically instantaneous change in fuel without loss of output from the unit being fired. This feature makes a standby fuel instantly available.
5. The ability to burn pulverized fuels of very low volatile content or fuel containing considerable water, as ignition can be maintained, when not otherwise possible, by also burning simultaneously a small quantity of another fuel such as oil or gas.

Fig. 2 shows a convenient and reliable form of high capacity combined burner for firing three fuels. It is a true combined burner in that all three fuels may be burned simultaneously if desired. It is not necessary to remove a part of the burner for firing one fuel in order to insert a part of the burner for firing another fuel. The combustion air for the fuel being fired sweeps over and cools those parts of the burner for firing the other two fuels. A change over can be made almost instantaneously.

The gaseous fuel is admitted to the furnace throat in an annular stream issuing from the inner periphery of the ring-shaped gas chamber immediately adjacent to the furnace throat opening. The gas impinges on the rapidly rotating column of air from the curved blades of the air register.

The pulverized fuel and carrier air are admitted tangent to the inner periphery of the rifled coal burner body located coaxially and adjacent to the gas chamber. This stream is picked up and mixed with the secondary air from the register rotating in the same direction.

The liquid fuel issues from the wide range mechanical atomizer tip in a diverging conical sheet which just clears the furnace throat surface. All the rotating combustion air from the register must pass through this sheet.

Fig. 3 shows a similar combined burner for lower capacities. In this burner the coal is admitted tangentially into a ring-like volute-shaped coal chamber and delivered to the furnace throat through an annular slot in the inner periphery of the chamber. The gas chamber is located between the coal chamber and the furnace front plate.

In the commercial application of these combined burners for firing waste fuels numerous combinations of gaseous, pulverized and liquid fuels of various types are encountered.

In addition to natural gas, many kinds of industrial gases are being fired by such units, among these being refinery still gases. Such gaseous fuels sometimes have a heat content per cubic foot as high as 2200 B.t.u. When burning these gases it is sometimes difficult to obtain the best appearing furnace conditions, due to the presence of a large percentage of the heavier hydro-carbons, and also because there may be present considerable quantities of raw distillate in suspension. Of course, whenever possible, the raw distillate should be properly removed in a separator, as its irregular entrainment in the gas continually changes the heat liberation of the burner and makes steady furnace conditions impossible. This is accentuated when operating with low excess air. It is obvious that for the proper combustion of such fuels, rapid and complete mixing of the fuel and air is essential.

Among the waste pulverized fuels being fired by these burners are various forms of petroleum coke. Depending upon the process from which this material is derived, it may contain from four to twelve per cent of volatile matter, and varying percentages of sulphur and ash. However, the ash content is normally low, and its fusing point high, although in certain instances fuels containing ash having a fusing point as low as 2000 deg. fahr. are encountered, and proper provision must be made to handle these. Refinery coke is often less firable than ordinary bituminous coal, but it is burned readily in pulverized form unless its composition approaches that of a pitch.

When burning a low volatile fuel particularly in a water-cooled furnace, the combined burner is very desirable as it provides an auxiliary fuel which is available immediately, and in such a way that the

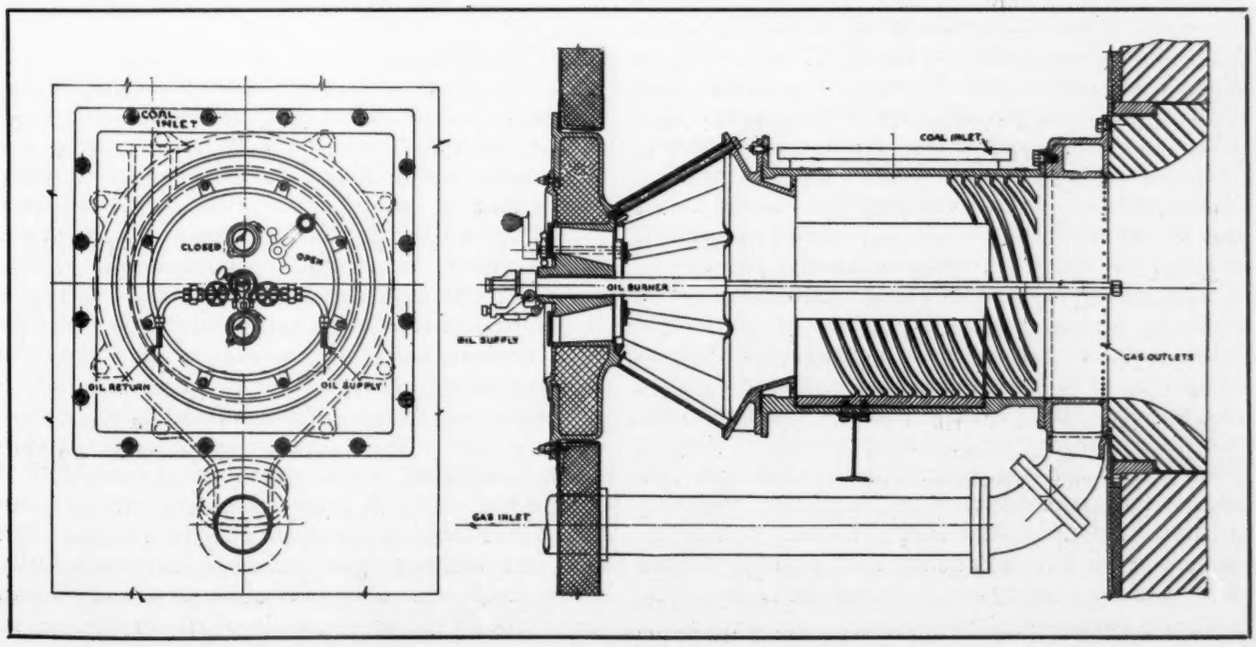


Fig. 2—Front elevation and cross section of high capacity combined coal, gas and oil burner.

control and operation of the plant are in no way complicated. In burning such pulverized fuels, it is necessary that proper combustion equipment be used, or else delayed ignition will occur and the combustible loss due to unburned carbon in the fly ash will be excessive.

The liquid fuels which are encountered often are of high specific gravity and contain a considerable amount of solid matter, carbonaceous or otherwise, in non-colloidal suspension. Mechanical atomization long has been recognized as the most economical method of burning liquid fuel, but not until recently has it been considered practicable for burning fuels of this nature.

Apparently one of the reasons for the previous inability to handle acid sludge in particular, and refinery sludges in general, in mechanical atomizers, was because capacity control by the use of inlet pressure variation was employed. Furthermore, it had been taken for granted that the mechanical atomizer must handle the fuel under exactly the same conditions as the steam atomizer and due to the high standard of operation expected from the mechanical atomizer it was at the same time required to produce far better results before being considered successful.

It is well known that ordinary fuel oil cannot, in all cases, be handled with as little treatment as is required for the atomizer, and it is generally admitted that the slight additional preparation is warranted by the superior furnace conditions and better net economy with the mechanical burner. The proper procedure for economical sludge firing with mechanical burners for such fuels is, therefore, obvious.

Extensive tests indicated that, with a little preparation, refinery sludges could be burned satisfactorily in the Peabody wide-range mechanical atomizer of the circulating type. As a result of these tests, an installation was made at the Louisiana Station of Louisiana Steam Products, Inc., at Baton Rouge, Louisiana, and the operating results have more than borne out the experimental data. The burners at this plant are successfully firing crude or lubricating (acid) sludge, soda bottoms, neutralized sludge, acid tar, and wax tailings in addition to fuel oil. Combined burners are employed as it also is necessary to fire pulverized and gaseous fuels.

This same type of wide-range mechanical atomizer is firing various grades of asphalt pitch, which, while solid at atmospheric temperatures, melt at temperatures up to 125 deg. fahr., depending upon the source. When such pitches are delivered from the process to the burners at temperatures varying from 300 to 600 deg. fahr., their viscosity is sufficiently low to enable them to be atomized properly without additional heating. The use of fuels delivered at the burners at such elevated temperatures has made it necessary to use special materials for the atomizer parts subject to pressure. Such atomizers are also finding frequent use for firing other liquid residual fuels encountered in the petroleum inudstry.

The ability of this design of mechanical atomizer to handle such fuels successfully is due largely to the wide-range feature of control. This feature ordinarily is used to obtain a continuous and positive control (it is not a "high-low" burner) over a wide range of burner capacity, without reducing the fineness of atomization, and without the necessity for changing atomizer tips. This is of particular importance in a plant with a widely fluctuating load when firing into a "black" furnace where the method of changing the supply pressure to take care of load range leads to coarser atomization at the

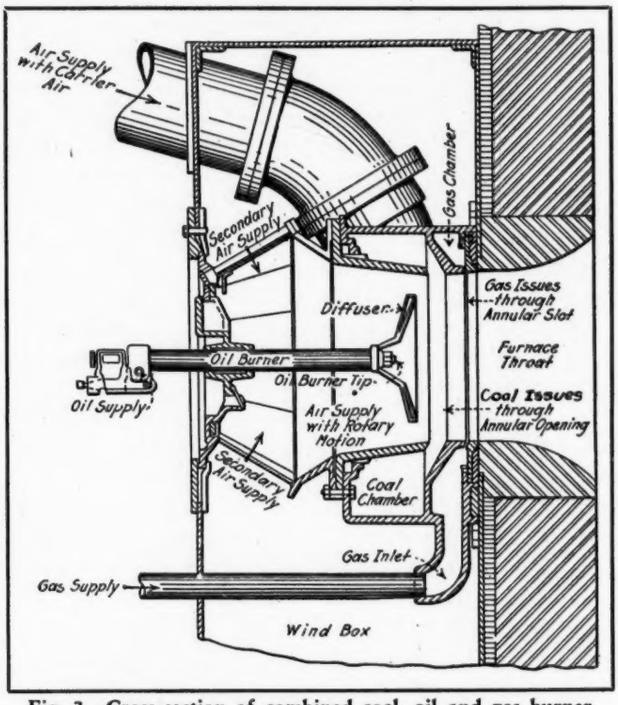


Fig. 3—Cross section of combined coal, oil and gas burner for lower capacities than the burner shown in Fig. 2.

lower capacities. Due to the existence at these lower capacities, of a lower heat liberation per unit of furnace volume, furnace conditions tend to become poorer under the best of circumstances, and coarse atomization seriously accentuates the trouble. When such conditions are coupled with increased burner capacities and the use of waste fuels, which require the maximum fineness of atomization at all capacities to produce the best results and which are far more sensitive to variation of supply pressure than ordinary fuel oils, it can be seen that the ability to operate over a wide range without affecting the atomization is almost essential.

In the case of heavy liquid fuels containing a considerable amount of foreign matter in non-colloidal suspension, the wide-range feature, providing circulation, has the very important added value that all of the fuel entering the burner is not necessarily sprayed. In this way, a continuous circulation of fuel through the atomizer tip of the burner can be maintained at all times, part of the fuel supplied

entering the furnace, and part being returned to the tank. All dead ends are eliminated, the atomizer tip is cooled by the excess amount of circulating fuel, and the velocities can be kept sufficiently high to prevent such solid matter as is present from settling out and plugging. Tendency to carbonize in the atomizer tip is greatly reduced due to the additional cooling effect of the circulating fluid.

The wide-range mechanical atomizer of the circulating type can be changed to a steam atomizer merely by changing the atomizer tip. In this form, one atomizer has fired successfully approximately 9,000 lb. per hr. of acid sludge. Gas atomization by the use of high pressure refinery gas has also been used to produce corresponding heat liberations, but as an atomizing agent, gas is not quite so effective as steam. However, as this gas is often available at high pressure and must be disposed of, the quantity of atomizing gas is of relative unimportance, and every bit of atomizing agent acts as fuel contrary to conditions obtaining when using steam for this purpose. In the case of steam the most desirable furnace appearance often is obtained with an abnormal amount of atomizing steam and if the operator is not careful, the quantity of atomizing medium may reach an excessive figure.

Combined burners of the type shown in Fig. 4 have been purchased to fire two 600 lb. pressure boilers at the new steam station of the Humble Oil and Refining Company at Baytown, Texas. Each burner will fire approximately 4,000 lb. per hr. of fuel oil and each boiler is to produce 350,000 lb. of steam per hr. In addition to this, there will be burned various refinery sludges and natural gas. These burners are combined gas and oil burners. They are similar to the three-fuel burner shown in Fig. 1 but with the coal burner body omitted. Jackson & Moreland of Boston are the engineers for this project.

An excellent example of a station in operation where various waste fuels are used to full advantage is the Louisiana Station at Baton Rouge, to which reference has been made. There combined burners similar to those shown in Figs. 2 and 4 are firing successfully various kinds of refinery sludges, petroleum coke, natural gas, and fuel oil, under four boilers each having a capacity of 350,000 lb. of steam per hr., the boiler feed being treated Mississippi River water. Maximum operation represents about 850 per cent of rating based on the boiler heating surface. Stone & Webster Engineering Corporation of Boston, Massachusetts, is the engineer for this project.

This station is a typical public utility plant, utilizing the waste fuels from a refinery and supplying to the refinery process steam and electric current, which previously the latter produced in its own plant. It was described briefly in a paper presented before the Boston section of the A. I. E. E. on November 18, 1930, by H. J. Klotz of the Stone & Webster Engineering Corporation and will be further discussed by him on February 11, at the National Fuels Meeting in Chicago. As this station is the first of its magnitude to be arranged for waste fuel consumption in combined burners, its design and operation are of great interest to combustion engineers, and without a discussion of its fuel problems this paper would be incomplete.

The proportion of the heat supplied by the different fuels varies considerably, but averages about as follows, the fuel oil, which is used only for standby purposes, being neglected.

50 per cent natural gas
33⅓ per cent refinery sludges
16⅔ per cent petroleum coke

About 85 per cent of the sludges contain from 30 to 50 per cent of dilute sulphuric acid which gives them an actual acid content of about 12 to 20 per cent. Approximately one-half of the remaining 15 per cent of the sludges is strongly alkaline.

Some of the sludges fired at Louisiana are more or less readily "burnable" but lubricating (acid) sludge, proper, has in many cases caused considerable difficulty and the equipment heretofore developed in the refineries for burning it, has been designed primarily for the purpose of disposing of the fuel and not with the main object in view of obtaining efficient combustion. The combustion of the sludge usually has been the most convenient means of disposal and the mere ability to burn it has been considered an event.

This sludge is extremely variable in its characteristics, depending not only upon the initial crude stock but also upon the method of treating of that stock, including the amount and type of oil used for fluxing, as well as the method of agitating the flux with the sludge. Sludge often contains a large amount of suspended carbonaceous material, and one acid sludge may be practically solid and another rather fluid. It varies from day to day and from hour to hour. Some sludges have a heat content as high as 17,500 B.t.u. per lb., whereas others have a heating value as low as 8,000 B.t.u. per lb. This wide variation is accounted for largely by differences in the amount of flux which must be added to make the material flow, and by variations in the weak acid content. This latter often will run as high as 40 per cent. One sample of acid tar (which is considerably more fluid than the acid sludge) contained 54 per cent weak acid, i.e., acid and water, of which 38 per cent represented the acidity, which means that the tar contained 21 per cent of actual sulphuric acid.

The gravity of acid sludge may run from 5 to 14 deg. Baumé. The viscosity of the material cannot be determined, as the heavy and light components settle out in the viscosimeter, giving readings which are not at all representative of the true internal friction.

Lubricating acid sludge usually must be treated. This treatment ordinarily consists of fluxing with oil

or tar to reduce its viscosity. Sometimes a sludge cannot be made "burnable" by fluxing in this fashion and must have a caustic material added to it. This process changes it from acid to neutralized sludge. The proper viscosity cannot always be obtained by additional heating as some sludges tend to foam at a temperature slightly above 200 deg. fahr.

Sludges usually are kept in agitation in suitable lead or bricklined tanks by jets of steam or jets of steam and air. Quite possibly some method of mechanical agitation could be used instead of steam, but up to the present time this has not been done. In some plants it has been found impracticable to use tank heating coils as the sludge carbonizes on the outside of the coils, reducing the heat transfer. Furthermore, agitation such as is now accomplished by steam jets seems desirable.

The preparation of the sludge varies with its character and differs in many refineries. No definite rules can be laid down for its treatment. As to whether or not it is properly fluxed or sufficiently agitated, only visual observation of experienced operators can determine. About the only definite statement which can be made about it is that a properly prepared sludge will be smooth and not too granular.

Improper treatment will cause coking. Any coke particles which are precipitated from the sludge tend to coagulate and form larger lumps of coke. The acid in the sludge appears to hold the coke in a sort of semicolloidal suspension, and in certain cases, even if the sludge be boiled with heavy acid after the coke particles are precipitated, they will not again be absorbed by the fluid, but when boiled with a neutralizing agent, in some instances they can be made to return into suspension.

While the sludge itself is highly corrosive due to its sulphuric acid content it often seems to be more so when mixed with steam, as is indicated by the wear on steam atomizer nozzles. This may be accentuated by high velocity and the increased corrosive effect due to the presence of the steam at high temperature, and radiation from the furnace.

In firing boilers with acid sludge or acid tar, it is necessary to keep the exit gas temperatures above the dew point in order to prevent acid corrosion of the flues and certain portions of the heating surface. At Louisiana no acid fuels are burned when the boiler capacity falls below a value giving a final gas temperature below 275 deg. fahr. However, in the case of air preheaters where there are any dead pockets or points in which a local cooling effect may be obtained, there is a strong possibility even then that some corrosion will occur.

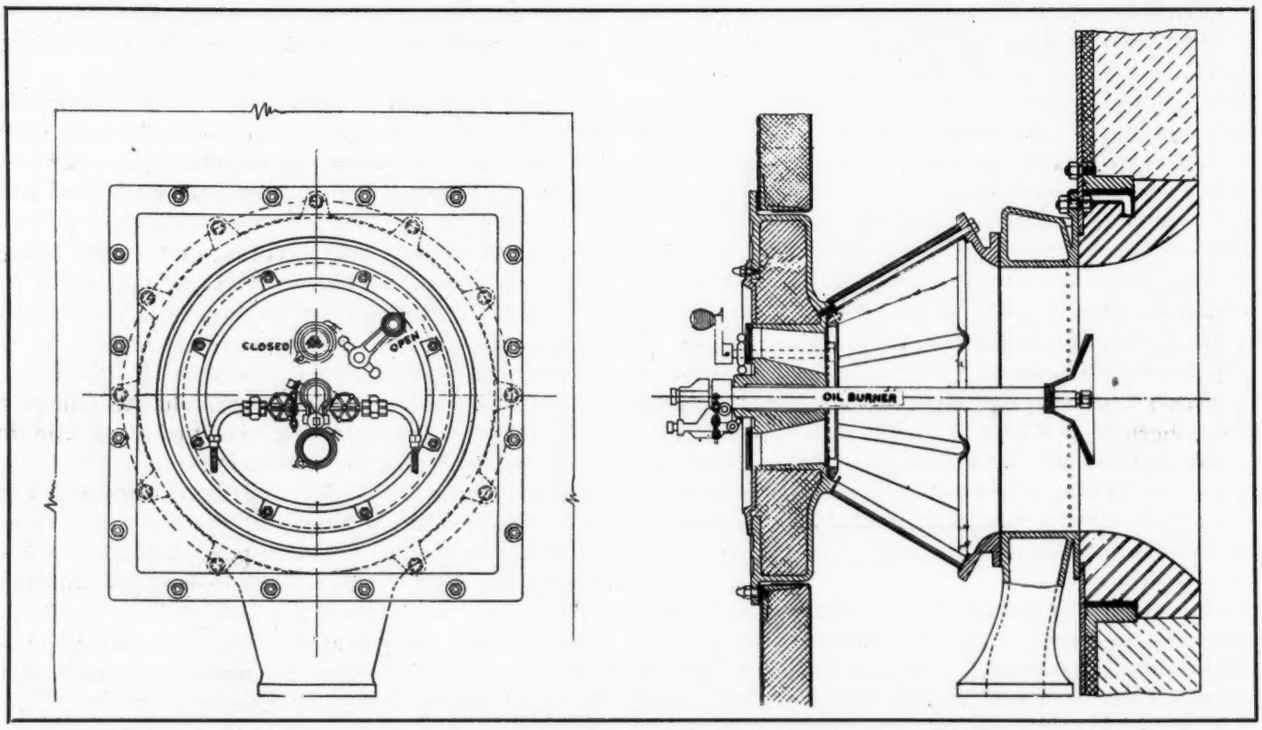


Fig. 4—Front elevation and cross section of combined gas and oil burner. In this design the coal burner body is omitted.

With some sludges, slag is deposited on the furnace bottom and on the boiler tubes, similar to the deposit obtained when firing pulverized fuel with relatively low fusing point ash.

The alkaline sludges such as soda bottoms and neutralized sludge do not attack ferrous metals so that the usual materials are satisfactory for piping and atomizer parts. Also, these sludges are generally more easily fired, and less variable in their characteristics than the acid lubricating sludge. Brickwork difficulties when burning alkaline sludges are experienced in many plants. Furthermore, with alkaline sludges, salt may be deposited on the boiler tubes, superheater and air preheater. This may

result in excessive draft losses unless ample soot blowing equipment is provided.

In the installation at Baton Rouge, each burner is designed to handle approximately 2,200 lb. per hr. of liquid sludge, or 1,600 lb. of fuel oil. In addition to the acid sludge, acid tar, neutralized sludge and soda bottoms, wax tailings, natural gas, petroleum coke and fuel oil also are burned.

The liquid fuel piping on each boiler front consists of two sets of headers, one of steel for the neutral or alkaline fuels, and one of brass for the acid fuels. All burners handling liquid fuels are piped to fire fuel oil which may be delivered in the steel header. The two bottom rows are piped to take their supply either from the acid or alkaline header, while the top row takes its supply from the alkaline header only. Each burner is equipped to fire gas.

Each of two of the four boilers is equipped with 18 combined gas and liquid fuel burners in three horizontal rows of six each. The two bottom rows of burners handle acid sludge. The top row handles neutral or alkaline fuels. All burners, of course, can be used for fuel oil or gas. In addition to the circulation through the acid sludge atomizers provided by the wide-range feature, the sludge supply header itself is connected to the same circulating pipe back to the tank to eliminate any dead ends in the supply header and prevent the deposition of coke therein.

Each of the second two boilers is fitted with 17 burners. There are six combined gas and liquid fuel burners of the usual size in the bottom row. In the second row are four of these combined burners with 2 Toronto Type combined pulverized coke and gas burners in the center of the row and in the top row five combined burners. The two bottom rows are for handling acid tar, oil and gas, and the top row for alkaline fuels, oil and gas.

Gas is always fired in some of the burners. This is because the amount of sludge is insufficient to provide for the total steam output. Also previous refinery practice seems to indicate that it is better to fire gas and sludge together, although this is not always done. The burners fire through the vertical front wall of the furnace and no ignition arches are provided. The interior surface of the furnace is water-cooled, part of the cooling tubes being covered with refractory material.

As might be expected in a plant of this magnitude, where the conditions are so new and the quantities so variable, some operating difficulties have been encountered. However, they have been surprisingly few and far less than had been anticipated.

Insofar as the combustion and furnace conditions are concerned, results are satisfactory. It sometimes happens when lighting off burners firing a new batch of sludge, that the first atomizers installed will plug, due to material which has collected behind the stop valves connecting the burner to the fuel header. However, once in operation the burners will stay clean for periods comparable with those between cleanings in a plant using ordinary fuel oil.

The question of the ideal material for burner tips has not been settled definitely. The difficulty of this problem will be realized when it is stated that in one plant using steam atomizers, brass tips have been eaten away in 48 hours. The tips originally supplied seem to have given the best service, although this is not so good as is obtained when firing fuel oil. The burner tips are being used as a convenient "laboratory" in which to test materials for other parts of the plant subject to corrosion, such as pump liners, heater tubes, valve trim, etc. Substantial progress has been made and new materials are in sight which give promise of being entirely satisfactory.

When it is considered that sometimes pulverized coke, sludge and gas are being fired simultaneously into one furnace it is obvious that the combustion problem is not a simple one. The fact that the operation has been carried on so successfully is a tribute not only to the designers and builders of the plant, but also to the operators.

This plant is only one of many plants where combined burners are being used for firing waste fuels. In other plants, waste fuels which have been successfully fired in the type of burners described are as follows:

1. Dubbs' Residuum, containing up to 30 per cent of base settlings and water and nearly 5 per cent of sediment by extraction.
2. Still gas, containing up to 10 per cent of hydrogen sulphide.

   Both of these fuels are fired in the same plant, the change from gaseous fuel to liquid fuel being made many times a day.
3. A mixture of gas oil and Holmes-Manley cracker bottoms.
4. 125 deg. fahr. melting point asphalt pitch.
5. Distillate containing a considerable amount of solid matter in suspension.

Combined burners are being used for firing units of various types. Some of the newer types of oil stills are vertical cylinders as large as 25 ft. in dia., the walls being formed by vertical tubes containing the fuel to be processed. Some of these are being fired from the bottom and some others from the top. The former method is now more widely employed.

In closing, please let me say that the refinery engineers were presented with an enormous problem when they had to dispose of these fuels, and the fact that for years they have been burning them is a testimonial to their ingenuity. They have contributed a vast reservoir of information, and if this had not been available, modern installations of waste fuel burning plants would be far behind their present state of progress. No one can have had any contact with the oil refining industry in this country, without developing a profound respect for the intricate problems involved, and the effective manner in which these are being solved.

Thermal Properties of Gaseous Mixtures

(*Continued from page 33*)

work due to the pressure of the gas behind it to which it is impermeable. The total work done would be

$$AW = m_a ART \log_e p/p_a + m_b ART \log_e p/p_b$$
$$= ART (m_a \log_e p/p_a + m_b \log_e p/p_b)$$

obtained from the relation derived for isothermal expansion of a perfect gas in the article on "Thermal Changes in Gases."

Now, in isothermal expansion of a perfect gas, heat must be added equal to the work done. Hence, in mixing gases in a reversible manner through the use of semi-permeable pistons, an amount of heat must be added equal to the work done if the temperature is to be maintained constant. Therefore, the internal energy and total heat of the mixture will be the same as if mixture had occurred by the irreversible process of diffusion.

It is not practical to mix gases in the above reversible manner because no perfectly semi-permeable membranes are available for use as described. The process of "rectification" for separating liquefied gases might be operated in a reverse manner for mixing gases but this also is theoretical rather than practical. The above discussion, however, provides a basis for calculating the efficiency of actual rectification processes. Thus, to separate atmospheric air at 68 fahr. into oxygen and nitrogen by a reversible process, would require per mole of air,

$$AW = 1.985 \times (68 + 459.6)(0.21 \log_e 1/0.21 + 0.79 \log_e 1/0.79) = 538 \text{ B.t.u.}$$

This is equivalent to $538/0.21 = 2560$ B.t.u. per mole of oxygen, or $2560/3415 \times 385.3 = 0.00195$ kw-hr. per cu. ft. of oxygen. These processes actually require 0.04 to 0.05 kw.-hr. per cu.ft. of oxygen. Hence, the efficiency of these processes varies from 4 to 5 per cent.

•

Blow-Down Losses and Their Correction

(*Continued from page 28*)

from wells that have a hardness of from 17 to 20 grains per gal. There is no sulphate hardness but the water actually carries some sodium carbonate. The atmospheric evaporation is sufficient to give the spray pond a bicarbonate hardness of approximately 12 grains and excess sodium alkalinity of 2 grains. Since calcium carbonate will not form scale at a heating surface unless concentrated sufficiently to bake on the metal, no treatment was required for scale prevention. Again sludge removal deconcentrators were used to remove the calcium carbonate as fast as it was formed in the boilers. Since the aeration process in the spray pond had removed all free carbon dioxide and since such conditions would allow of the formation of scale on the cooling surface of the feed water lines some means were required to prevent this. Accordingly some ferrous sulphate was fed into the heater discharge. This reacted with some of the sodium carbonate to form sodium sulphate, ferrous hydroxide and free carbon dioxide. The free carbon dioxide so formed prevented pipe line incrustation by dissolving calcium carbonate that was formed in the heater. Sodium sulphate was formed in sufficient amount to give a sulphate carbonate ratio sufficient for the 185 lb. pressure carried on the boilers. The ferrous hydroxide took up any free oxygen in the water and thus prevented oxygen corrosion and at the same time formed ferric hydroxide which coagulated the suspended calcium carbonate and carried it in circulation until it was deposited in the deconcentrator. No boiler blow down was required and the water loss from sludge removal in the deconcentrators was less than 1 per cent of the evaporation.

These illustrations, while they do not cover the entire range of possibilities, indicate that any system of boiler water conditioning should be chosen only after careful calculation of its efficiency for that particular case. If the individual plant operator has not the necessary experience to calculate all of the chemistry and physics it will be decidedly worth while to consult some expert on this subject. The formulae in the first paper and illustrations here presented should form a guide at least to a better understanding of the importance of correcting blow-down losses.

•

The Chemical Nature of Coal

(*Continued from page 25*)

as undoubtedly in time they will be, men will wonder at the slowness and obtuseness of the present generation in the matter.

Now, however, that the scales have fallen from our eyes, may it not be hoped that both chemists and engineers will now look upon coal, with its natural benzenoid structure, as a raw material of vastly greater potentialities than ever before appreciated, and that they will combine in well-directed efforts to realize them.

Having dealt in this article with what seems to be the probable nature of the main coal substance, in my next article I shall discuss the benzene-pressure-extracts from coals and their bearing upon the maturing of coals and the development in them of coking propensities. Meanwhile anyone interested in the subject who wishes to have full details of the researches referred to will find them in the Proceedings of the Royal Society, London, A *105* (1924) p 523; *110* (1926) p 537; *120* (1928) p 523 and *127* (1930) p 480.

The Removal of Sulphur from Chimney Gases

The Latest Developments in Great Britain, Primarily in Connection with the New Battersea Station, London

By
DAVID BROWNLIE
LONDON

American steam plant practice has long recognized the need of avoiding air pollution by eliminating the emission of dense smoke and preventing the discharge of grit and smudge from chimney tops. . . . Local conditions dictate the extent to which industrial wastes may become public nuisances. For instance, on the open road, the exhaust from automobiles is widely dissipated and hence constitutes no menace. However, in vehicular tunnels, these same gases would be closely confined and the air would be quickly devitalized were not mechanical ventilating systems provided to remove the toxic gases and introduce fresh air. . . . Due to peculiar local conditions, the City of London, has found it desirable to extend the campaign against air pollution to include the removal of sulphur from the combustion gases discharged from power stations located in the metropolitan district. . . . The present article is the third contribution by Mr. Brownlie during the past two years on British developments in the removal of sulphur from chimney gases.

•

IN March last, the author described the experimental work that had been undertaken by the London Power Company, at its Grove Road Power Station, London, in connection with the washing of combustion gases with hot water so as to remove the obnoxious sulphur dioxide and sulphur trioxide, this work having originated because of the public opposition to the erection of the new Battersea Power Station on the Thames.[1] There was also included in the previous article, a detailed reference to the Ministry of Transport (British Government) Report, Cmd. 3442-1929, essentially an Interim Report by the advisers to the London Power Company in connection with the methods suggested to prevent damage by sulphur products in the chimney gases from power stations, with particular reference to the Battersea station.

As a result of the first part of the work, as described in the report, and relating to investigations undertaken between April and August 1929, it was learned that about 500,000 cu. ft. of flue gases result for every ton of coal burnt, and that it is a practical proposition to wash these gases with hot water, at a temperature of 150 to 190 deg. fahr., as, by this method it is possible to remove about 96 per cent of the total sulphur products when using only 17 to 21 tons of water per ton of coal burnt. Further, it was stated that the water of the Thames is sufficiently alkaline, equivalent to about 17 to 20 parts per 100,000 C_aCO_3, to take all this acid water without neutralization.

During the past month or two, however, important new developments have taken place in England which are of the greatest interest, and we are definitely approaching the time when every power station will have to operate with a completely innocuous chimney top, that is, under conditions of almost total elimination of black smoke, dust and grit, and acid sulphur compounds.

The opposition to the erection of power stations in the center of London has again been stirred into violent activity because of the proposal of the Fulham Borough Council to erect a huge power station, of 318,000 kw. ultimate, at Fulham, on the Thames. This proposed installation, essentially an extension of their present small plant is being strongly opposed by many sections of the community, led by the London County Council.

If this projected extension at Fulham is allowed to go through, then there will be four power stations, Lots Road (Chelsea), the Battersea Council Station, the new Battersea Station of the London Power Company, and the proposed Fulham Station, within a mile of one another, right in the heart of London, with a population of over 7,000,000 people. Obviously the situation is becoming impossible as regards the discharge of untreated combustion gases from power stations, located in the metropolitan area.

Meanwhile the erection of the first section of 120,000 kw. at Battersea, is proceeding, and is to be ready by the end of 1932. The operation will, of course, be watched very closely by many different interests, while the degree of success in the treatment of the chimney gases will undoubtedly constitute an important precedent for power station practice throughout the world.

[1] Sulphur Fumes in Stack Gases, by David Brownlie, COMBUSTION, March, 1930.

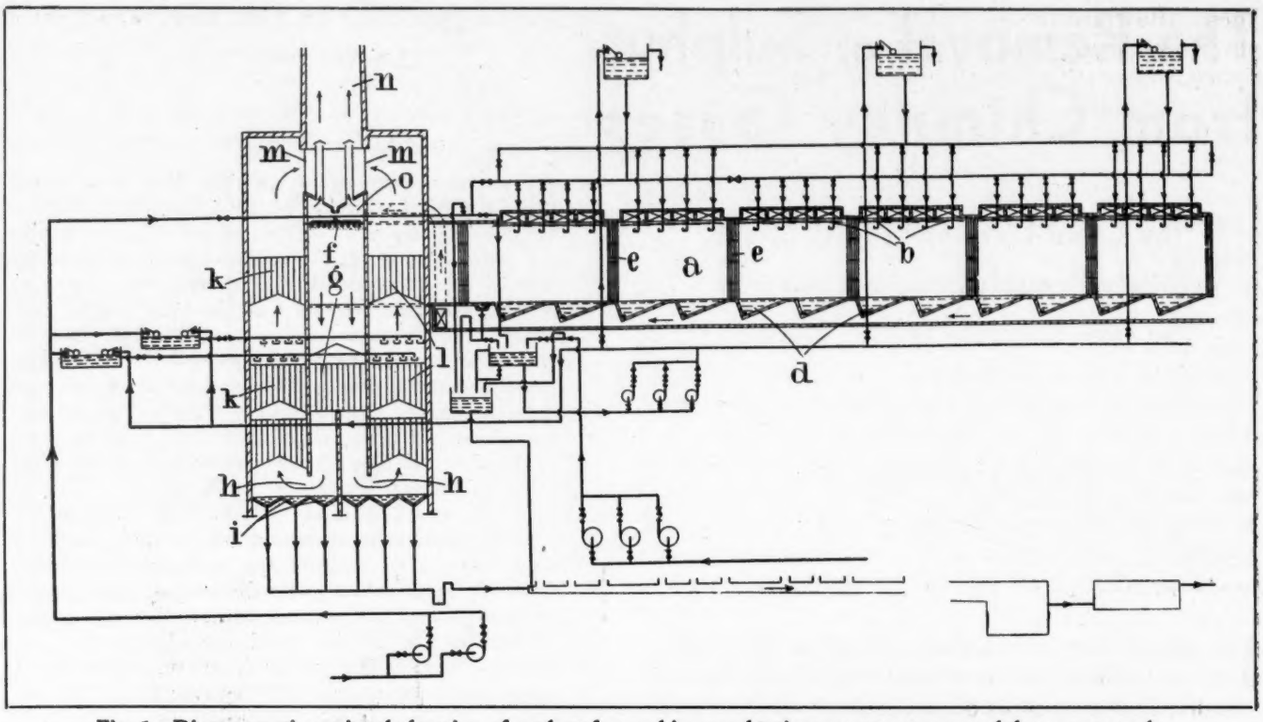


Fig. 1—Diagrammatic sectional elevation of a plant for washing combustion gases to remove sulphur compounds.

Black smoke no longer represents a problem to any self-respecting station, while experience in Great Britain during 1930 has confirmed beyond doubt that the problem of dust and grit removal from chimney gases has also been completely solved. One well-known British make of centrifugal and gravity collector is now separating from 70 to 95 per cent of the total dust, and in most cases over 85 per cent. More than 75 power stations in Great Britain are already equipped on these lines, and altogether there are over 500 collectors in service at industrial and power station plants, separating more than 150,000 tons of dust per annum. This extensive experience has shown that with mechanical stokers, from 0.5 to 5.0 per cent of the weight of coal burnt is discharged from the chimneys as dust, while with pulverized fuel firing, the figures are of an amazing character, often as high as 15 per cent of the coal. A number of medium sized power stations in Great Britain are separating from 150 to 250 tons of dust per week, the remaining material in the combustion gases being extremely small, practically in the "cloud" stage, with particles less than 50 microns, and often below 10 microns.

There recently appeared an interesting British patent[1] relating to the design of the plant that is now being installed at Battersea for washing the chimney gases with hot water sprays, and, if necessary, finishing with a dilute alkali such as lime water or sodium carbonate solution. Evidently there is some doubt as to whether hot water alone will be sufficient, despite the first report which stated that due to the alkalinity of the Thames it would not be necessary to neutralize the acid water resulting from washing the chimney gases.

The essential claim of this patent is a method for treating combustion or other gases for the removal of obnoxious products by causing these gases to pass through a horizontal chamber or conduit containing a number of spray-washing compartments, in which the gases are thoroughly saturated by liquid, water or otherwise, in a heated condition and separated by baffle board scrubbers or partitions of packing material, after which the gases enter a second vertical chamber with a changed direction of flow, where they are subjected to a thorough douching by means of sprays or curtains of liquid, water or otherwise as before, with a final passage through scrubbers.

As is pointed out in the patent, many previous attempts have been made to wash gases by means of water sprays or similar methods, but hitherto these have not been satisfactory for the removal of sulphur products from combustion and other gases, and particularly as regards sulphur dioxide (SO_2), which is not readily soluble in water.

Fig. 1, reproduced from the patent, is a diagrammatic sectional elevation of the general arrangement, although for the purpose of clearness the left-hand portion comprising the uptake is shown turned at an angle of 90 deg. to its proper position. Fig. 2 is a sectional plan view of part of Fig. 1, on a somewhat reduced scale, with the left-hand portion in its correct position, while Fig. 3, is a cross-section on the line 3–3 of Fig. 2.

[1] British Patent 334,660, London Power Company and S. L. Pearce (Chief Engineer.) Application, July 16, 1929, Acceptance, September 11, 1930.

These illustrations are primarily intended to apply to an entirely new boiler plant, originally designed to include flue gas washing equipment, a different matter in many cases from dealing with existing boiler plants.

All of the boiler combustion gases pass through the long primary chamber *a*, at the top of which are fixed a considerable number of water sprays *b*, generally using hot water at 175 to 180 deg. fahr. The main function of these sprays is to saturate the gases with moisture. At this stage there may also be installed, as shown in the plan view Fig. 2, a series of grit extractors *c*, which will take out a large part of the dust before the gases pass in to the saturator chamber.

The water from the sprays falls into a series of hopper-like receptacles *d*, located at the bottom, and forming collecting channels. Here it is suitably treated for neutralization of the acid, or discharged directly into the river if the river water is sufficiently alkaline. This main separator chamber *a* is divided into a number of compartments, of which six are shown in the drawing, separated from one another by baffle board partitions or scrubbers *e*.

The combustion gases enter at the right of Figs. 1 and 2, pass through each of the compartments in the long separator chamber and then travel into a vertical spray-washing chamber, rectangular in cross section, containing a series of force sprays *f*, while at the same time the direction of flow is altered sharply and the gases are made to pass through a series of scrubber devices *g*, which can be made of wood or any other suitable material such as fireclay, metal, earthenware, or porcelain. After this the direction of the gases is again changed, as shown

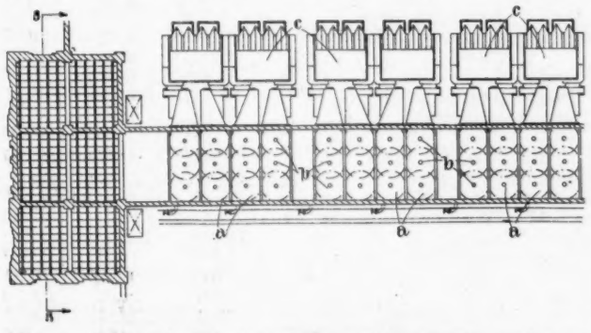


Fig. 2—Sectional plan view of plant shown in Fig. 1, shown in reduced scale.

for example at *h* in Fig. 1. This reversal of direction assists the deposition of entrained water which is collected in the troughs *i* at the bottom.

The gases then pass up through an additional series of scrubbers *k* and *l*, and here there may be used a diluted alkaline solution, such as soda ash or lime, as final treatment to complete the separation of the acid sulphur products. Next, the flue gases pass upwards through moisture eliminators *m*, formed as before of a series of small baffles of wood, metal, or other suitable material, and are finally discharged to the chimney *n*. At this stage there can be added to the gases, which are of course completely saturated with moisture, a current of hot air from the chamber *o*.

Although a specific temperature of 175 to 180 deg. fahr., is mentioned for the saturating and scrubbing water, this, as well as the alkaline solution, can be

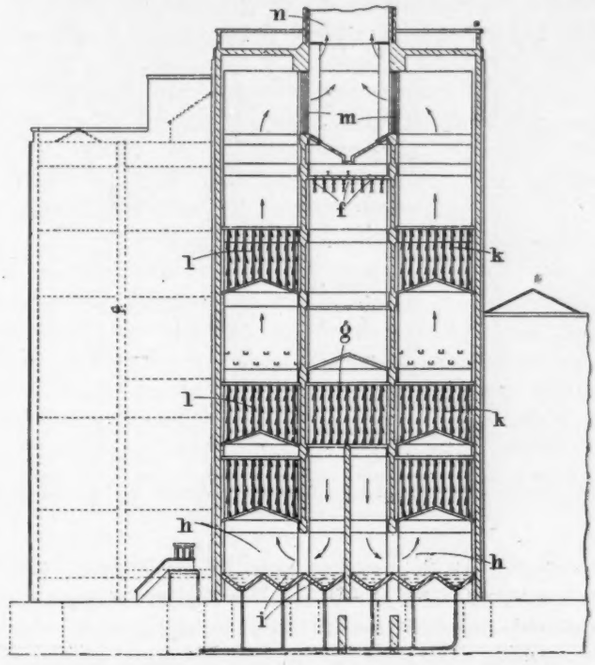


Fig. 3—Vertical cross section of plant on line 3-3 of Fig. 2.

varied to suit the actual conditions. There is now claimed in the patent, the addition of ozonized air, if necessary. This presumably is to be added to the combustion gases before they enter the saturator chamber with the primary object of assisting the oxidation of the sulphur dioxide to the more soluble sulphur trioxide.

The general arrangement of the main suction fan with the dust collector is shown in Fig. 4, the gases being taken by the fan *c* from the top of the main flue behind the boiler, passing through the collector and then being discharged to the primary separator chamber *a* shown on the left, with the hot water sprays *b* at the top.

A second Report of the Ministry of Transport, entitled "Treatment of Sulphur Fumes in Connection with the Working of the Proposed Electric Power Station of the London Power Company at Battersea" has recently been issued,[3] being the second report of the advisers to the London Power Company, together with the report of the committee presided over by the Government Chemist.

There is contained in this second report, a description of the investigations that have been carried out by the London Power Company at its Grove Road Power Station since the date of issue of the first

[3] Cmd. 3714, price 4d net, H. M. Stationery Office, Adastral House, Kingsway, W.C. 2, London.

Ministry of Transport Report, Cmd. 3442, published in 1929, as already described by the author in a previous article in these columns.

The first part of this later work was carried out on the original small experimental plant at Grove Road, the gist of which was to show that the main cause of the oxidation of sulphur dioxide to the more soluble sulphur trioxide is the presence of iron, which acts as a catalyst. Subsequently there was

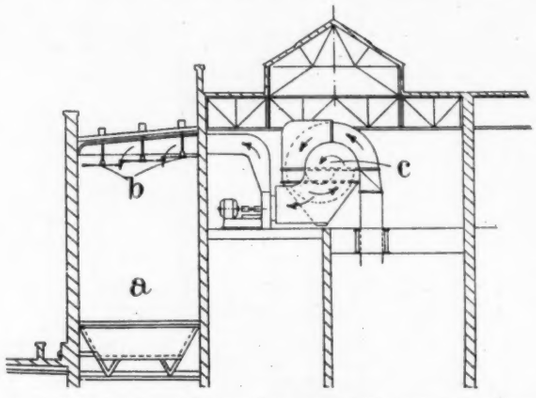


Fig. 4—Cross section showing fan, dust collector and primary saturation chamber.

erected at Grove Road, on Boiler No. 26, a large-scale gas washing plant. This plant was apparently designed and constructed independently and before the results described in the first Ministry of Transport Report, were known.

This large-scale installation at Grove Road is illustrated in Fig. 5, which shows the elevation and cross section. In this design, the boiler flue gases after first passing through a centrifugal dust collector, enter three horizontal washing chambers or tunnels arranged side by side in parallel; each of these tunnels is 34 ft. long, 9 ft. 9 in. high and 2 ft. 9 in. wide. Finally the gases pass through a vertical tower 34 ft. high and of rectangular cross section, 12 ft. x 7 ft. 6 in., containing pottery rings 4 ft. deep. Powerful water sprays are fitted both in the horizontal tunnels and in the vertical scrubbing tower. The results obtained at this installation are given in Table I.

This second report of the Ministry of Transport is short and not written very clearly, while no information is given concerning the vital point of the cost of the installation.

When the gas washing plant was carefully coated inside with cement, to prevent any contact with iron, the average elimination of sulphur from the gases, at varying boiler loads, was only about 20 per cent of the total. Presumably, warm water was used the amount of water varying from 12 to 40 tons per ton of coal burnt. When, however, a large number of corrugated iron sheets was placed in the horizontal tunnels, the amount of sulphur products extracted was increased considerably, the average figure being 44 per cent as compared with the previous 20 per cent, so that evidently iron plays an important part catalytically in oxidizing the sulphur dioxide to sulphur trioxide. Further, when the boiler was operating at half load, the previous experiments having been conducted under normal load, then the amount of sulphur products extracted rose to 67 per cent. If final washing with an alkaline carbonate of soda solution is carried out, then a total elimination of 97 per cent of sulphur products is obtained. However, the object of experiments of this kind is a mystery, since it is well known that sulphur dioxide and sulphur trioxide can easily be removed from gas by washing with a strong alkali, the obvious objection being the enormous cost of dealing with a vast volume of flue gases corresponding to about 500,000 cu. ft. per ton of coal burnt.

The report states that the Advisory Committee to

TABLE I

RESULTS OF TESTS OF EXPERIMENTAL GAS WASHING PLANT, BOILER No. 26, GROVE ROAD STATION, LONDON POWER COMPANY, LTD.

(From Ministry of Transport [British Government] Report Cmd 3714 November 1930)

	Full load.	*Half load.*	*Half load and Alkali.*
COAL.			
Lb. per hour	8,630	4,690	4,330
Carbon per cent.	63.2	65.9	65.8
Sulphur per cent.	0.90	0.89	0.84
GAS.			
Cu. ft. per ton coal @ 60 deg. F.	375,000	490,000	485,000
Average CO_2 content of inlet gas per cent.	11.3	8.9	9.1
Temperature of inlet gas deg. F.	229	231	225
Temperature of outlet gas deg. F.	75	83	96
Cu. ft. per hour @ average temperature of 152 deg. F., 157 deg. F. and 160 deg. F., respectively	1,690,400	1,206,400	1,107,600
Inlet gas, SO_2 m.gms. per litre N.T.P.	0.90	0.57	0.93
" SO_3 " "	0.90	0.68	0.49
Total S " "	0.81	0.56	0.665
Total S grains per cu. ft. "	0.354	0.245	0.29
Outlet gas, SO_2 m.gms. per litre "	0.43	0.13	0.019
" SO_3 " "	0.59	0.31	0.026
Total S " "	0.451	0.185	0.02
Total S grains per cu. ft. "	0.197	0.081	0.009
Per cent. removed SO_2	52	77	98
" SO_3	35	54	96
" Total S	44	67	97
WATER AND EFFLUENT.			
Tons per ton of coal	27	50	13½ plus* alkali.
Gallons per hour	23,100	23,100	5,845
SO_2 grains per gallon	13.4	6.0	28.4
SO_3 "	8.0	14.3	42.1
Total S "	9.9	8.7	31.0
(or parts per 100,000)	14.1	12.4	44.3
Total Fe grains per gallon	2.5	1.7	8.9
(or parts per 100,000)	3.6	2.4	12.7

*The smaller quantity of water is explained by the use of increased contact surface.

SULPHUR BALANCE SHEET.	lb.	lb.	lb.
Coal S. per hour	77.6	41.7	36.4
Inlet gas "	73.0	36.0	38.8
Outlet gas "	41.2	11.9	1.2
Effluent "	32.6	28.7	39.2
Ash "	2.15	0.7	0.7
Column 3, in addition to the water used, alkali was re-circulated at the rate of 300 gallons per hour and contained:—			
S, grains per gallon 305	....	....	13.1
These figures are included in the above balance sheet.			
TIME OF PASSAGE OF GAS IN FREE SPACE IN SECONDS.			
Horizontal—1st Section 11 ft.	2	3	3
" —2nd Section 23 ft.	4	6	6
Vertical (effective) 15 ft.	2½	4	4

the London Power Company is convinced that with ample capacity of gas washing plant, as will be the case at Battersea, and allowing a sufficient time factor, with the presence of ironwork to act as a catalyst, the elimination of sulphur dioxide and sulphur trioxide should reach at least 80 to 85 per cent without the use of any alkali, although provision has been made in the Battersea plant for this alkali treatment if necessary.

The actual installation that is now being made at Battersea, is based essentially on British Patent 334,660, already described, but with a long primary saturator chamber.

The report also states that the advisers have received from the London Power Company an estimate of the capital costs, and that on this estimate they consider the scheme to be commercially practicable for Battersea. However, no detailed information is given, which seems to be a strange proceeding and of course tends to raise considerable doubts on this aspect of the question.

According to the comments made on this report by the British Government Committee, presided over by the Government Chemist, the alkali to be used at Battersea to complete the treatment would be milk of lime. It is also stated that the process seems to be capable of improvement in other directions, including cost. Here again, no detailed information is given. Also the question of the effect of the effluent which is to be discharged to the Thames and the attitude of the Port of London Authority on this important matter, are not clear.

Finally, while this contribution was being written (end of December 1930) there was in progress in London, a public inquiry by the Electricity Commissioners (British Government) into the application of the Fulham Borough Council for permission to extend their small existing generating station in Townmead Road, Fulham, This extension, as projected would be equivalent to building a new station of 318,000 kw. capacity. This development is most strongly opposed by the London County Council, and by a number of other important local authorities, including the Borough Councils of Chelsea and Kensington, the Westminster City Council, the Trustees of the National Art Gallery, the London Society, and many other interests.

At this time it is impossible to give the results of these proceedings, but one point that came out in the early stages was the claim that the Fulham Borough Council has erected an experimental plant for treating boiler gases to remove sulphur compounds, and this is in actual operation on a large scale, on one boiler. No detailed information is yet available concerning this plant except that the flue gases, washed with water as usual, are caused to pass along a large tunnel containing at intervals a series of tubes from which the water is sprayed into the gases. The method is therefore another modification of the principle of spraying with water. Obviously, the main point is the question of capital cost, especially as the use of forged drum boilers for high steam pressures is already raising very considerably the investment costs incident to the production of electricity.

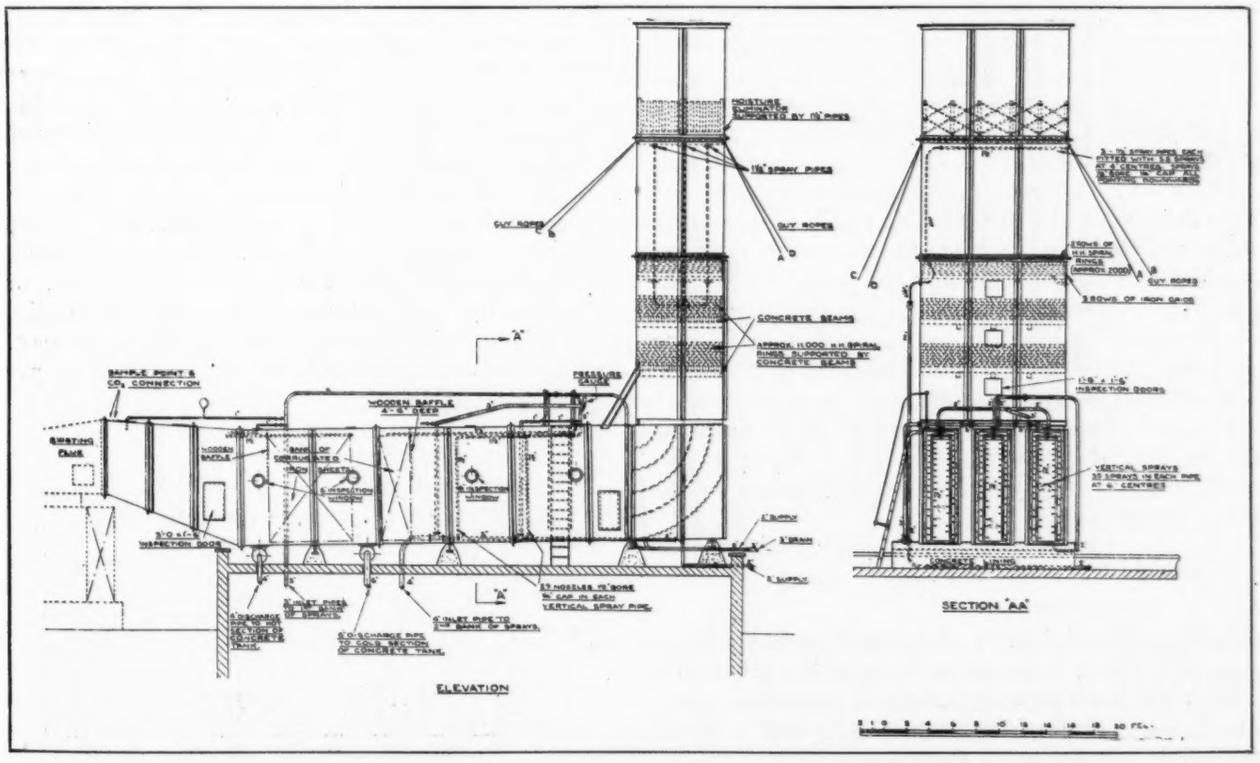


Fig. 5—Elevation and vertical cross section of experimental gas washing plant, Grove Road Station, London Power Company, Ltd.

How to Compute Stack Sizes

By B. J. CROSS

Combustion Engineering Corporation, New York

THE computation of stack proportions is not an exact procedure as some of the values involved must be assumed and others approximated. A high degree of accuracy in the calculation is therefore not justified.

Draft as produced by stacks is the result of the difference in weight of the column of hot gases in the stack and an equivalent column of air at the atmospheric temperature. Kent's equation for the determination of this difference in weight expressed in inches of water is:

$$h = H\left(\frac{7.64}{T_2} - \frac{7.95}{T_1}\right)$$

where h is the draft in inches of water, H the height of the stack in feet and T_2 and T_1 the absolute temperatures of the air and stack gases respectively. 7.64 and 7.95 are constants derived from the densities of air and flue gas at 32 deg. fahr. The density of air is taken as .0807 and that of flue gas .084 lb. per cu. ft. This corresponds to the weight of flue gas containing 10 per cent Co_2 which is probably higher than the average figure. The average temperature of the stack gases, T_1 may be assumed at 80 per cent of the temperature of the entering gases.

The draft as determined by this equation is the maximum theoretical draft or static draft which obtains only under conditions of zero velocity. This draft could be measured at the base of a stack when the damper is closed and the stack contains the hot gases. When the damper is opened and the gases attain velocity, some of this draft is used in accelerating the gases and some is lost in friction between the moving gas and the surface of the stack. The effective or available draft at the stack damper is equal to the theoretical or static draft minus the loss in draft due to friction and that due to velocity.

The loss of draft due to friction is given in the following equation:

$$h_r = f\,\frac{H}{D}\,\frac{V^2}{T_1}$$ *

in which H is the height of the stack in feet. D the diameter in feet, V the gas velocity in feet per second and T_1 the average temperature of the stack gases. The factor f is the friction coefficient and is given the value .008 for brick lined stacks.

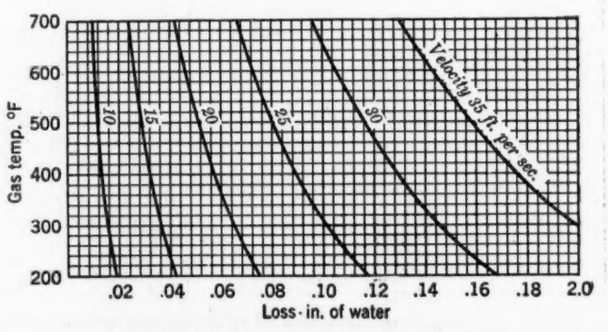
*Menzin—Transactions A. S. M. E., Volume 37, Page 1069.

The expression for the loss of draft due to the acceleration of the gases is derived from the basic equation $v = \sqrt{2gh}$. This equation reduces to:

$$h_v = .1235\,\frac{V^2}{T_1}$$

in which h_v is the acceleration loss in inches of water. In all of the three equations, the atmospheric pressure is assumed at 30 in. of mercury. The small chart below gives the acceleration loss for various velocities and temperatures. When determined, this loss should be added to the required draft at the stack damper.

In the chart on the opposite page the maximum theoretical draft h_m and the friction loss h_r have been plotted for a 100 foot height of stack. The maximum theoretical draft depends only upon the temperatures of the stack gases and the air. It is given on the right hand vertical scale. The friction loss depends upon gas temperature, gas velocity and stack diameter. The available draft equals the theoretical draft minus the friction loss. To determine the friction loss, the volume and temperature of the gases to be handled must be known. Various combinations of gas velocity and stack diameter must be known. Various combinations of gas velocity and stack diameter may be tried. Thus, in the example chosen for a gas temperature of 425 deg. fahr. a gas velocity of 30 ft. per sec. and a stack diameter of 6 ft., the friction loss is .135 in. of water per 100 foot of stack. If a stack 8 ft. in dia. were selected the velocity would be 17 ft. per sec. and the friction loss would be .04 in. of water per 100 ft. of stack height.



Loss of draft due to acceleration of gases.

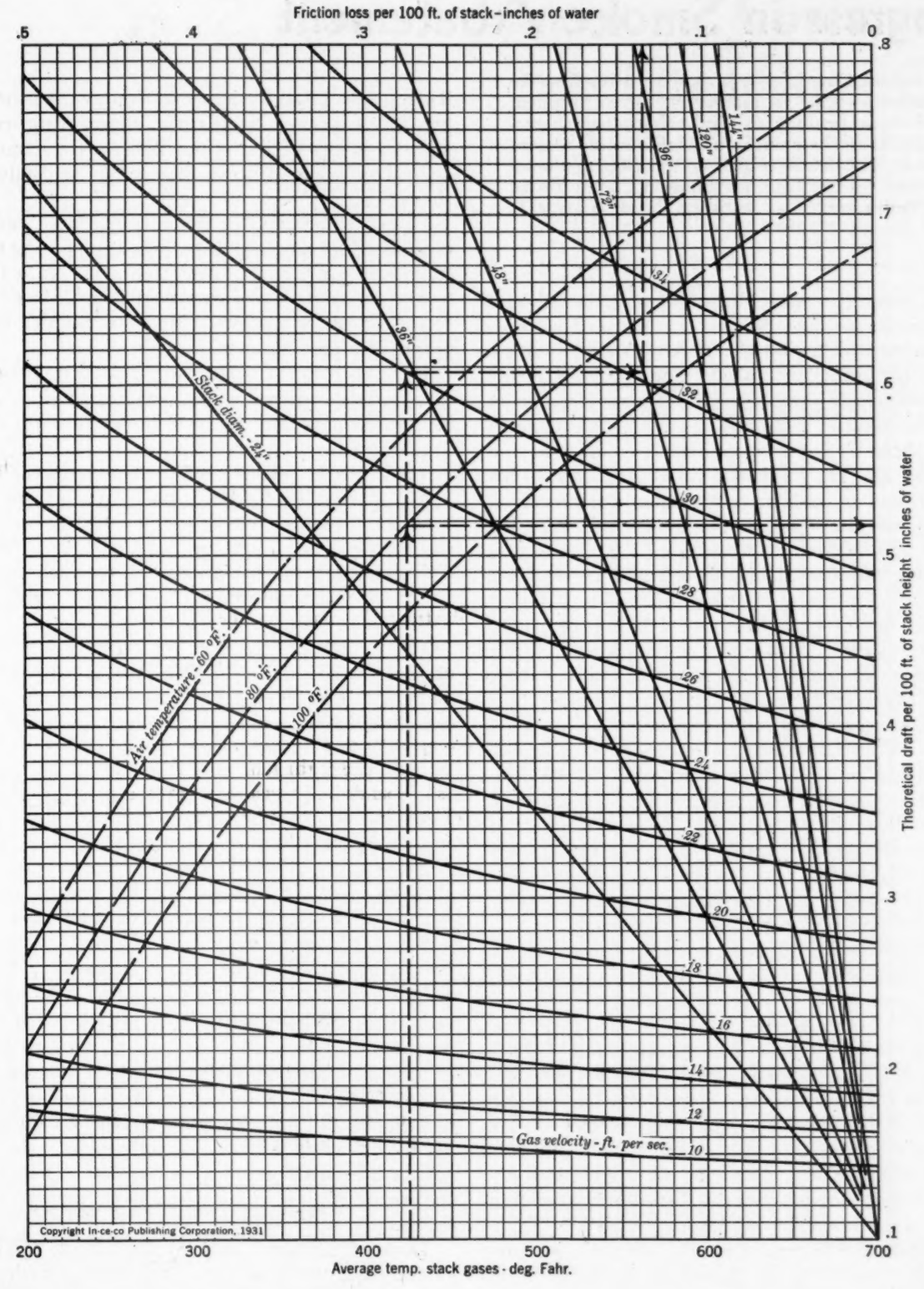


CHART SHOWING THEORETICAL DRAFT AND FRICTION LOSS PER 100 FT. OF STACK HEIGHT

No. 19 of a series of charts for the graphical solution of steam plant problems.

Progress in Smoke Abatement

Hudson County, N. J., has adopted a smoke ordinance which Dr. Harvey N. Davis, President of Stevens Institute of Technology, has characterized as the best smoke ordinance in the United States. The details related on this page are based on news releases from the Hudson County Board of Health and Vital Statistics, dated January 21 and January 27, 1931.

THE Hudson County Board of Health and Vital Statistics on January 20, 1931, adopted a smoke ordinance, prohibiting the making of dense smoke within the limits of Hudson County, New Jersey, and establishing a Department of Smoke Regulation. This ordinance is based on the standard smoke ordinance of the U. S. Bureau of Mines, which was compiled by Dr. O. P. Hood, Chief Engineer of the Bureau, and an authority on smoke abatement.

The new Hudson County smoke ordinance was drawn up under the direction of Col. Elliott H. Whitlock, former Smoke Commissioner of Cleveland, Ohio, and now in charge of smoke abatement research at Stevens Institute of Technology, Hoboken, New Jersey, and William G. Christy, former Executive Secretary of the St. Louis Smoke Abatement League and recently appointed Smoke Abatement Engineer of Hudson County.

Col. Whitlock made a remarkable record in eliminating smoke in Cleveland, and is considered an expert on smoke abatement work. Yesterday, in commending the Officials of Hudson County for tackling the smoke problem, Col. Whitlock stated that this is the first time in the history of the United States that a County government has passed a smoke ordinance and set up a smoke department.

The new smoke ordinance creates a Department of Smoke regulation under the Board of Health and Vital Statistics in charge of a Smoke Abatement Engineer. In drawing up the Ordinance Col. Whitlock and Mr. Christy had the assistance of Mr. H. K. Kugel, Acting Smoke Commissioner of Cleveland. Kugel is Chairman of the Smoke Abatement Committee, Fuels' Division, American Society of Mechanical Engineers. He recently collected and compiled smoke ordinance from every American city having such an ordinance. This collection comprises over 200 smoke ordinances.

Dense smoke is defined in the ordinance as being equivalent to No. 3, or greater on the Ringelmann Chart, or as being so thick at the point of emission that it cannot be seen through. The new Hudson County smoke ordinance prohibits the production or emission of dense smoke, fly-ash or fumes from any smoke stack or open fire, except that from a locomotive or steam boat, for a period or periods aggregating two minutes in any period of fifteen minutes. It also prohibits smoke equivalent to No. 2 of the Ringelmann Chart from any stationary plant or open fire for a period or periods aggregating twelve minutes in any period of one hour. No. 2 smoke is defined as being so dense that it can be dimly seen through.

From a locomotive or steam boat, dense smoke is prohibited for a period or periods aggregating thirty seconds in any period of three minutes. No. 2 smoke from a locomotive or steam boat is prohibited for a period or periods aggregating four minutes in any period of fifteen minutes.

The Ordinance also requires that any person or corporation constructing, or reconstructing, altering or repairing any furnace, boiler furnace, stack, or any apparatus connected with a stack, shall secure a permit for such work from the Smoke Department.

Any person or Corporation violating any prohibition or requirement of the new smoke ordinance is subject to a fine not exceeding fifty dollars ($50.00) or imprisonment in the county jail or workhouse for not more than thirty days, or both. Each day's violation constitutes a separate offense.

The Ordinance provides for an Advisory Board of three engineers who will act in an advisory and consulting engineering capacity to the newly established Department of Smoke Regulation. According to an announcement dated January 27, 1931, the Board of Health and Vital Statistics has appointed Dr. Harvey N. Davis, Chairman of the Advisory Board, with Roy V. Wright, newly elected President of the American Society of Mechanical Engineers, and Colonel Elliott H. Whitlock, Research Professor of Mechanical Engineering in charge of Smoke Abatement at Stevens Tech. The Advisory Board serves without compensation except for a nominal fee when they actually meet.

Hudson County is indeed fortunate in having three such outstanding mechanical engineers of national reputation as advisors to its new smoke department.

In addition to being President of Stevens Institute, Dr. Davis is Vice-President of the American Society of Mechanical Engineers and a member of other leading societies and scientific organizations. He is the author of several technical books and has served as consulting engineer for various Government Departments.

Through his work in Cleveland, Col. Whitlock gained recognition as one of the leading authorities on smoke abatement in the United States. He is a graduate of Stevens and a member of various Engineering Societies.

Roy V. Wright is President of the American Society of Mechanical Engineers. For the past twenty years, he has been Managing Editor of "Railway Age" and is an authority on the fuel and smoke problem of railroads.

Third International Conference on Bituminous Coal

Discoveries in the field of fuel technology that have been made during recent years in all parts of the world will be disclosed at the Third International Conference on Bituminous Coal which will be held at the Carnegie Institute of Technology, Pittsburgh, in November, 1931. Previous congresses held in 1926 and 1928 have attracted to Pittsburgh outstanding scientists from at least seventeen countries, and the meetings are now looked upon by men concerned with coal as the place where the latest developments in fuel are revealed. The following announcement of the plans and tentative program for the 1931 conference has been prepared especially for COMBUSTION.

•

IN the interest of the Third International Conference on Bituminous Coal, Dr. Thomas S. Baker, president of the Carnegie Institute of Technology, and organizer of the previous meetings, is now visiting scientists in the principal cities of Europe to investigate the work being done in laboratories there and to invite prominent fuel technologists to deliver addresses at the Pittsburgh meeting.

According to a preliminary announcement, papers will be given on carbonization, liquefaction and gasification of coal, the mechanism of combustion, cleaning of coal and its preparation for the market, pulverized fuels, power plants, and domestic heating.

While the discussions will be concerned principally with new uses for bituminous coal, industries that affect the soft coal business will figure prominently in the program. Thus, in the first draft of the program are included such subjects as the role of natural gas in the public utility field, gas versus coal, discussed from the angle of both industries, economic trends in heating, the use of natural gas, and the economics of manufactured gas.

Representatives of the research laboratories of several industrial concerns dealing with coal and coal products will be invited to give their findings in the by-products field. Among the proposed subjects in this section are constitution of tar, resins from light oil, ammonia disposal, wood preservation, hydrogen from coal, new by-products from manufactured gas, lamp black, utilization of ash as a by-product, low temperature carbonization, carbon electrodes, utilization and washing, pulverizing and carbonization, hydrogenation, combustion of coke, and the use of tar in retorts.

In the field of domestic heating, the committee proposes to have discussions on small stokers, central heating plants, atomized coal, domestic coal distribution and heat transportation.

New processes being used in coal cleaning and preparation will be discussed from various angles by representatives from the several fields.

The subjects mentioned represent but a brief sketch of the entire program. What the European technologists will contribute will be announced later by Dr. Baker.

Before Dr. Baker's departure for Europe he organized an advisory board composed of prominent American men of affairs. This group will assist the organizing committee in determining general policies to be pursued. The men who accepted Dr. Baker's invitation to serve in this capacity are: Mr. James A. Farrell, president of the United States Steel Corporation; Mr. John Hays Hammond, prominent mining engineer; Mr. Samuel Insull, public utilities magnate; Mr. Frank B. Jewett, president of the Bell Telephone Laboratories, Inc.; Hon. A. W. Mellon, secretary of the United States Treasury and capitalist; Mr. F. A. Merrick, president of the Westinghouse Electric and Manufacturing Company; Mr. Auguste G. Pratt, president of the Babcock and Wilcox Company; Mr. H. B. Rust, president of the Koppers Company; Mr. Matthew S. Sloan, president of the New York Edison Company; Mr. Gerard Swope, president of the General Electric Company; and Mr. W. C. Teagle, president of the Standard Oil Company of New Jersey.

The meeting held in 1926, attracted 1700 scientists from thirteen countries. The addresses given at this meeting were edited and published by the Institute of Technology.

A more ambitious program was undertaken at the second meeting two years later when 2200 persons representing seventeen countries attended the congress. Developments since the first conference were completely covered, and a second set of proceedings, this time in two volumes, was published.

The purpose of the congress was briefly summarized by Dr. Baker in an interview before his departure for Europe when he said:

"The whole point of the conference is the hope that we shall find new uses for bituminous coal. As the scientists present their papers covering new processes, discoveries and uses of the various derivatives of coal, it is our expectation to point out the application of these discoveries, what they will mean as possible new outlets for our surplus coal. This basic world industry is now suffering acute depression, and we hope that we may be of assistance in helping it on the road to recovery."

PROGRAM—Fifth Midwest Power Engineering Conference - - Fourth National Fuels Meeting - - -

These two important meetings will be held at the Stevens Hotel, Chicago, the week of February 10, 1931, concurrent with the Fifth Midwest Power Exposition. The Fourth National Fuels Meeting is sponsored by the American Society of Mechanical Engineers, and the Fifth Power Engineering Conference by the Local Sections, Regional and Professional Divisions of the following societies: American Society of Civil Engineers—American Institute of Mining Engineers—American Institute of Electrical Engineers—American Society of Mechanical Engineers—American Society of Refrigerating Engineers—National Electric Light Association—Western Society of Engineers—National Safety Council.

FIFTH MID-WEST POWER ENGINEERING CONFERENCE

FEBRUARY 10-12, Incl., 1931

Tuesday, February 10th

9:00 A.M.—Registration—Stevens Hotel.

12:00 Noon—Luncheon.
Pres. H. W. Fuller presiding.
"Power and Its Effects on the Methods and Progress of Modern Civilization."

2:15 P.M.—Power Economies Session.
Chairman, *C. F. Hirshfield,* The Detroit Edison Co.
"Balancing Plant Investment with Operating Cost."
A. H. Kehoe, United Electric Light & Power Co., New York.
"Advance in Electrical Distribution."
H. W. Eales, Byllesby Engrg. & Mngmt. Corp., Chicago.
"Dual Purpose Power Plants and Commercial Distribution of High Pressure Steam."
John M. Drabelle, Iowa Railway & Light Co., Cedar Rapids, Iowa.

8:00 P.M.—Refrigeration and Ventilation Session.
Chairman, *Alvin H. Baer,* Frick Co.
"New Application of Refrigeration in Air Conditioning."
Willis H. Carrier, Pres. Carrier Engineering Co., Newark, N. J.
"The Future of Central Station Refrigeration."
George Horne, Merchants Refrigerating Co., New York.

Wednesday, February 11th

9:30 A.M.—Prime Movers Session.
Chairman, *Alex D. Bailey,* Commonwealth Edison Co.
"Trends in Steam Turbine Development."
Prof. A. G. Christie, Baltimore, Maryland.
"Reciprocating Engines for the Higher Steam Pressures."
John F. Ferguson, Chicago.
"The Influence of Use on the Design of Internal Combustion Engines." *H. F. Shepherd,* Cooper-Bessemer Corp., Mt. Vernon, O.
"Water Turbines of the Propeller Type."
L. F. Harza, Harza Engineering Co., Chicago.

12:00 Noon—Luncheon—American Institute of Mining and Metallurgical Engineers.
Chairman, *C. C. Whittier,* R. W. Hunt Co., Chicago.
"High Temperature Metals for the Power Plant."
L. W. Spring, Crane Company, Chicago.

2:15 P.M.—Late Developments in Electrical Field Session.
Chairman, *R. F. Schuchardt,* Com. Edison Co., Chicago.
"Power Requirements for the Pumping of Oil, Gas and Gasoline."
Audley E. Harnsberger, M. E. Pure Oil Co., Chicago.
"Arc Welding in the Power Plant."
W. H. Zorn, Detroit Edison Co., Detroit, Mich.
"Distribution of Electric Power with High Voltage Direct Current." *C. W. Stone,* General Electric Co., Schenectady, N. Y.

Thursday, February 12th

10:00 A.M.—Water Problems of the Power Plant Session.
Chairman, *Prof. F. G. Straub,* U. of Ill.
"Late Developments in Pretreatment of Boiler Feed Water."
S. T. Powell, Baltimore, Maryland.
"Developments in Evaporator Practice and Design."
F. S. Collings, Sargent & Lundy, Chicago.
"Concentration Control of Boiler Water."
H. S. Whiton, Byllesby Engrg. & Mngmt. Corp., Chicago.

12:00 Noon—Luncheon with Fuels Meeting.

2:15 P.M.—Civil Engineering Session.
Chairman, *Maj. R. W. Putnam,* Chicago.
"Geology and Reservoir Power Plants."
Dr. M. M. Leighton, Chief of Ill. Geological Survey.
"Engineering Features of the Chicago Subway."
Major R. F. Kelker, Chicago, and *Robert Ridgway,* New York.

7:00 P.M.—Banquet and Ball—Hotel Stevens.
Held jointly with the Fuels Division, A. S. M. E.
Address by *A. O. Caldwell*—Editor "Electronics," New York.

FOURTH NATIONAL FUELS MEETINGS

FEBRUARY 10-13, Incl., 1931

Tuesday, February 10, 1931

9:00 A.M.—Registration—All Day—Stevens Hotel.

Wednesday, February 11, 1931

9:00 A.M.—Registration—Hotel Lobby.

2:15 P.M.—Session.
A. E. Grunert, Efficiency Engineer, Commonwealth Edison Co., Chicago, Ill., Chairman.
"Use of Refinery Waste Fuels in Modern Steam Plants."
H. J. Klotz, Stone & Webster Engrg. Corp., Boston.
"The Economics of Fuel Utilization."
A. L. Brown, Consolidation Coal Co., New York, N. Y.
"New Processes of Dehydrating Low Grade Coal."
Dr. Max Toltz, Consulting Engineer, St. Paul, Minn.

8:00 P. M.—Session.
E. L. Beckwith, President Mid-West Stoker Assn., Chairman.
"Symposium on Small Stokers."
Presented by *T. A. Marsh,* Modern Coal Burner Co., Chicago, for Midwest Stoker Assn.
"Utilization of Anthracite Coal."
C. A. Connell, Gen. Mgr., Anthracite Coal Service, Philadelphia, Pa.
"Conversion of Coal Fired Boilers and Furnaces to Gas Firing."
W. D. Edwards, Consulting Engineer, Memphis, Tenn.

Thursday, February 12, 1931

10:00 A.M.—Session.
J. Van Brunt, V. P. Engrg., Combustion Engineering Corp., New York, N. Y., Chairman.
"Slag Tap Furnaces."
A. L. Baker, Sargent & Lundy, Inc., Chicago, Ill.
"Developments in Pulverized Fuel Firing."
H. Kreisinger, Combustion Engineering Corp., New York.
"Lighting Pulverized Fuel."

12:00 Noon—Luncheon Session.
W. Trinks, Professor of Mechanical Engineering, Carnegie Institute of Technology, Chairman.
"Recent Developments in Bituminous-Coal By-products."
A. C. Fieldner, U. S. Bureau of Mines, Washington, D. C.

2:15 P.M.—Session.
Geo. F. Gebhardt, Professor of Mechanical Engineering, Armour Institute of Technology, Chairman.
"Effect of Fineness of Pulverization on Boiler Efficiencies."
E. H. Tenney, Union Elec. Light & Power Co., St. Louis.
"Radiation in Boiler Furnaces."
N. Artsay, Geo. A. Orrok Co., New York, N. Y.
"Reduction of Unaccounted for Losses in Boiler Tests."
W. F. Davidson, Brooklyn Edison Co., Brooklyn, N. Y.

6:30 P.M.—Banquet and Ball.
Jointly with Midwest Power Conference.

Friday, February 13th

10:00 A.M.—Session.
A. A. Potter, Dean of Engrg., Purdue University, Chairman.
"Selection of Steam Generating Equipment."
F. H. Rosencrants, Combustion Engineering Corp., New York.
"The Pioneering Element in the Boiler Plant of the Future."
Geo. A. Orrok, Consulting Engineer, New York, N. Y.
"Changes in Character of Mid-West Coals and Stoker Performance."
E. L. McDonald, K. C. Power & Light Co., Kansas City, Mo.

2:00 P.M.—Session.
John Hunter, Consulting Engineer, St. Louis, Mo., Chairman.
"The Fly Ash Problem."
H. N. Bubar, Dust Recovery, Inc., New York, N. Y.
Round Table Discussion of "Air Polution Problems," led by *Col. Elliott H. Whitlock,* Stevens Institute of Technology.
Ely Hutchison, Editor, *Power,* New York, N. Y.

NEWS

Pertinent Items of Men and Affairs

New York Edison Output for 1930 Exceeds 1929 Demand

The generating station net output of electrical energy of The New York Edison System of companies in 1930 was six and one-half per cent greater than the output for 1929, Matthew S. Sloan, president, has announced.

The 1930 output amounted to 4,983,507,819 kilowatt hours of electrical energy, which was 304,795,921 kilowatt hours greater than in 1929.

Also the highest demand for electrical energy on the System in 1930—called the instantaneous peak load—was 1.8 per cent greater than the peak in 1929. The 1930 peak, which came at 5 p.m., December 23, was 1,247,800 kilowatts, which is equivalent to approximately 1,672,650 horsepower being used at one time.

Final Plans Announced for Oil Burner Show

Final plans for the eighth annual convention and show of the oil burner industry to be held in Philaphia, April 13-18, were completed at a meeting of the directors of the American Oil Burner Association in Philadelphia January 14. Convention meetings, it was announced, will be held in the Ben. Franklin Hotel while the exposition will be staged on the exhibit floor of the Gimbel Building across the street.

Harry F. Tapp, Executive Secretary of the Association, disclosed that 115 out of a total of 125 booths had already been reserved by members. The sale of space, Mr. Tapp said, indicates a greater interest in the show this year than ever before.

•

Illinois Testing Laboratories, Inc., 141 West Austin Avenue, Chicago, Illinois, announces the appointment of James H. Knapp Co., 4920 Loma Vista Avenue, Los Angeles, with a branch in San Francisco, as exclusive Pacific Coast distributor of its products for industrial purposes, consisting of "Alnor" and "Price" Indicating Pyrometers, Resistance Thermometers and other electrical and magnetic measuring instruments.

•

The Hays Corporation, Michigan City, Indiana, manufacturer of combustion instruments, has begun construction of a new steel and brick foundry building adjoining the present factory to provide an additional 6000 square feet of manufacturing space.

New Film Shows Modern Coal Preparation Methods

The Pittsburgh Coal Company, First National Bank Building, Pittsburgh, has announced a new motion picture film which presents the complete story of the development of "Champion Coal" and shows all of the steps of mining, cleaning, sizing, special mixing and loading.

District offices of the Pittsburgh Coal Company, located in the chief industrial centers, are equipped to show this motion picture to engineers, operators and executives who are interested in the preparation of quality coal.

Engineers from the company's main office at Pittsburgh are available to show the film and give talks before engineering societies, technical associations and other groups who may be interested in studying the latest developments in coal preparation.

•

The American Oil Burner Association, 342 Madison Avenue, New York City, has announced the appointment of Charles A. Whitney as a member of the technical staff of the association. Mr. Whitney was associated with the National Board of Fire Underwriters from 1912 to 1925 and has since been engaged in engineering and consulting work. In his new position, Mr. Whitney will spend most of his time in the field, working with municipal authorities in the drafting and modernization of ordinances relating to oil burner practice.

•

The Hahn Engineering Co., manufacturer of steam jet ash conveyors, storage tanks and ash gates, has moved its main office from Easton, Pennsylvania, to 30 Church Street, New York City. Eugene Hahn is in charge at the above address.

•

Col. T. S. Morrisey has resigned his position as Vice-President and General Manager of Combustion Engineering Corporation, Ltd., Montreal, to accept an executive position with United Engineers and Constructors (Canada), Ltd.

•

The Edward Valve & Manufacturing Co., East Chicago, Indiana, is now represented by the Dunbar Engineering Co., 122 East 42nd Street, New York City, in the territory formerly handled by representatives located at Philadelphia and Baltimore.

•

United Conveyor Corporation, Chicago, Illinois, manufacturer of ash conveyor systems and storage tanks, has opened an eastern sales office at 101 Park Avenue, New York City with J. J. McNulta, in charge of the New York and New England districts.

NEW EQUIPMENT

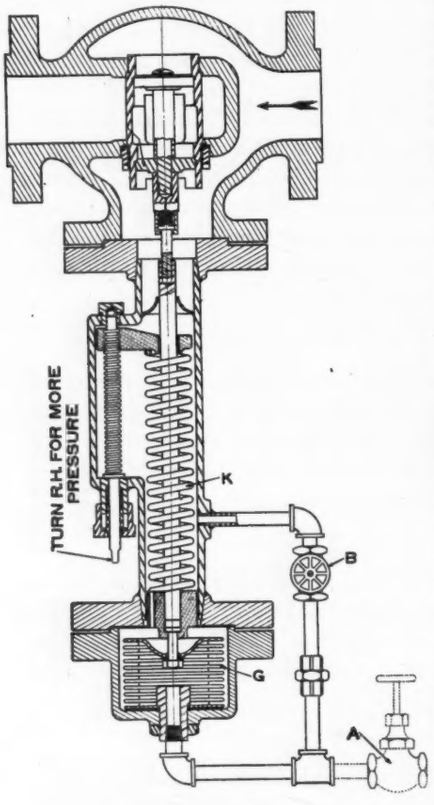
of interest to steam plant Engineers

A New Boiler Feed Pump Governor

THE Bailey Meter Company, Cleveland, Ohio, has announced a new boiler feed pump governor in the design of which several distinctive features have been incorporated.

The new boiler feed pump governor illustrated below is designed primarily for use with turbine driven pumps. Its purpose is to maintain a constant differential between the pressure of steam leaving the boiler and the pressure of feed water in the feed water lines. The governor is installed in the steam line to the turbine and controls the differential pressure by throttling the steam supply.

Feed water pressure is transmitted to the inside of the sylphon G this force being balanced by the steam pressure and the spring K on the outside of the sylphon. When the steam pressure decreases, the sylphon expands moving the valve mechanism upward, thus throttling the supply of steam to the turbine. In a similar manner more steam is admitted to the turbine when the steam pressure rises. To bypass the governor, valve A is closed and valve B is opened, thus equalizing the pressure on the inside and outside of the sylphon so that the spring will hold the valve in its open position.



The governor may be set for any desired differential by adjusting the spring tension by means of screw N. There are no glands or stuffing boxes on the valve rod so that its motion is not retarded and there is no tendency for the valve to leak.

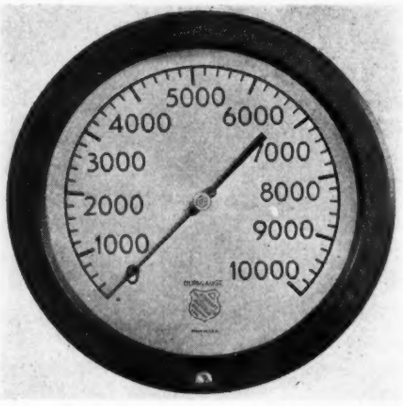
The valve is of the tight seating and fully balanced design and the entire seating arrangement can be easily installed or removed from the valve body without taking the body from the line.

Steam Gage For High Pressures and Temperatures

THE Duragage, a new steam pressure gage developed for the high pressures and temperatures of modern practice, has been announced by Consolidated Ashcroft Hancock Company, Inc., Bridgeport, Conn.

Accurate readings are secured over the entire range of the gage, through the use of an expansion tube which is bored out of a solid bar of special nitralloy steel selected because of its uniform expansion and contraction characteristics. Other parts of the gage are made of forged steel. An integral michrometer adjustment is provided so that the pointer may be set in the field to compensate for the weight of water in the connecting piping.

The cases are die cast and black hard-rubber finish is standard. Various designs



provide for wall mounting, flush-mounting and flush-mounting illuminated cases for panel boards.

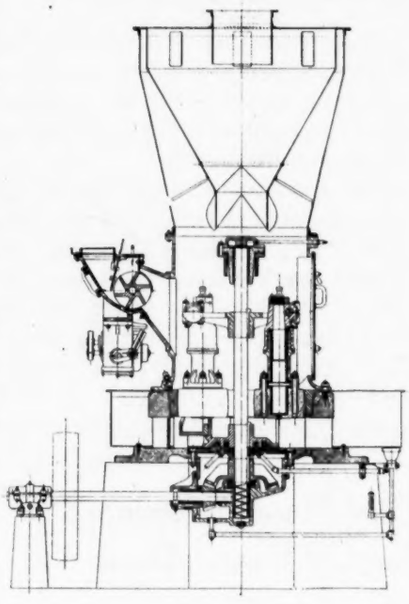
The Duragage is available in sizes from 4½ to 16 in. for all pressures up to 5000 lb. per sq. in. and in certain sizes for pressures up to 10,000 lb.

A Small Roller Type Pulverizing Mill

RAYMOND BROTHERS Impact Pulverizer Company, 1302 North Branch Street, Chicago, has developed a small pulverizing unit of the roller mill type for producing a finer, more uniform product with less power cost. This pulverizer is known as the Raymond Midget Mill, or No. 1 Roller Mill.

In power plants and in the metallurgical industries, cement plants and lime plants, where powdered coal is used, this mill is suitable for direct firing furnaces, kilns and similar heating or calcining units. When grinding coal, the capacity of the mill may be varied from as low as 1,000 lb. to as high as 4,000 lb. per hr., depending upon the fineness of grind and the physical characteristics of the coal.

The Raymond No. 1 Roller Mill is built on the same principle as the larger Raymond Roller Mills and Super Mills. It is of the suspended roller type, in which the rolls are



thrown out against the inside of a ring by centrifugal force, and grinding takes place between the rolls and ring. Plows are fitted ahead of each of the rolls to pick up material from the bottom of the mill and carry it to a point where it will be thrown between the rolls and ring. Three six-inch face rolls operate against the ring which is thirty inches inside diameter. The drive is through bevel gears and horizontal and vertical shafts, the gears operating in an oil-tight housing.

A positive feed device is provided. Attached to this feed device is a pneumatic feed control, which automatically controls the flow of material to the mill, as it is being ground, maintaining a full load on the machine at all times.

Power consumption is particularly low. The journals are of the oil-lubrication type. They use a very small amount of lubricant and do not require attention oftener than forty-eight to sixty hours.

The air-separating equipment is of the same type as used in the larger mills, including the special double cone air separator, exhaust fan, cyclone collector, tubular collector and connecting piping.

This mill may also be used as a Kiln Mill. Hot air or gases of combustion may be passed into the mill, making it possible to dry and pulverize in one operation. This eliminates dryers, elevators and conveyors. Drying and pulverizing in one operation is an advantage that saves on the initial installation cost, reduces the grinding cost, and simplifies operation.

This type of mill is also widely used in the chemical and processing industries as it is adaptable for grinding many materials which cannot be efficiently pulverized by the impact or hammer methods of grinding.

THE COCHRANE DEAERATING HEATER

is the improved, modern feed water heater

ITS use is conducive to the highest plant efficiency, as it utilizes bled steam or the exhaust of auxiliaries to heat the feed water in a regenerative feed heating system.

It can be operated at any pressure, from a high vacuum to a high back pressure, or under varying pressures.

It gives complete protection against oxygen corrosion to piping, economizers, boilers, superheaters and turbines, as it deaerates the feed water perfectly.

Its cost is but a little more than that of an ordinary open heater.

It can be combined with a storage or surge tank, a V-notch feed water meter (the most accurate known), or a hot process water softener.

COCHRANE CORPORATION

3160 North 17th Street, Philadelphia, Pa.

H-11

NEW CATALOGS AND BULLETINS

Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine

Desuperheater

Bulletin S-21-A describes the Swartwout Desuperheater and Governor. Modern boiler installations are generating steam at constantly higher temperatures and pressures. In many cases, however, steam at lower temperatures is still required, either for process work or for operating older equipment not designed to handle steam at high temperatures. To provide successful reduction for such plants, Swartwout offers a complete reducing and desuperheating station, which not only provides accurate control of pressure and temperature, but also can be arranged to protect any system against failure of supply in desuperheating water, or any other accident which might endanger low pressure, low temperature equipment. 4 pages, 7¾ x 10¾—The Swartwout Company, 18511 Euclid Ave., Cleveland, O.

Feedwater Conditioning

Three bulletins describe the American Lime Soda Water Softeners. Three types are presented, the cold process, the hot process and the semi-hot process. Each type is provided with an automatic electro-magnetic proportioner for controlling the chemical treatment. The three types of softeners are illustrated and each piece of equipment included in the system is shown and named. Brief descriptions of each type are given. 3 pages, 8½ x 11—American Water Softener Company, Lehigh Avenue and Fourth Street, Philadelphia.

Feedwater Heaters

The recent history of steam power plants is reflected in Bulletin No. 688, describing Cochrane feedwater heaters. The efficiency of non-condensing steam plants of thirty years ago was greatly improved by utilizing exhaust steam to heat the boiler feedwater to around 210 deg. fahr. Now, extracted or bled steam is utilized in high pressure condensing plants to heat the feedwater to well over 300 deg. fahr., not in one heater but progressively in a series of heaters, each receiving steam which has been expanded in the prime mover to the temperature to which the water is raised. By using a sufficient number of such bleeder heaters, the efficiency of the perfect thermodynamic cycle is closely approached. The feedwater heaters may take any one of a number of forms, including open heaters, closed heaters, deaerating heaters, metering heaters, vacuum heaters, back pressure heaters, jet heaters and storage heaters, as also hot process softeners, in which chemical treatment is combined with heating. Engineers who are interested in the operation or efficiency of boiler plants will find much to interest them in this publication. 48 pages, 8½ x 11—The Cochrane Corporation, 17th Street and Allegheny Avenue, Philadelphia.

Mechanical Drive Turbines

Bulletin GEA-1145A describes General Electric mechanical drive turbines, designed to operate stokers, fans, centrifugal pumps, compressors and similar machines. The principle of operation permits simplicity of design, substantial construction and large clearances between the wheels and stationary parts. In addition to the usual centrifugal governor, an overspeed emergency governor is furnished as standard equipment. This emergency governor operates an emergency valve which is separate and distinct from the speed regulating valve, and is closed by both steam pressure and gravity. Numerous illustrations are included to show details of construction and various application arrangements. 16 pages and cover, 8½ x 11—General Electric Company, Schenectady, N. Y.

Pipe Line Rust Preventive

No-Ox-Id presents a combined chemical and mechanical protection for steel against rust. It is particularly applicable to pipe lines, and investigations covering a period of over ten years have resulted in the establishing of specifications which assure positive prevention of rust. 10 pages, 4 x 8—Dearborn Chemical Company, 205 East 42nd Street, New York City.

Pressure Recording Gages

New bulletin No. 168 describes Foxboro Recording Gages. These instruments employ an alloy-steel helical spring with welded connections in order to meet the demands of high pressures and high temperatures. The construction combines safety with accuracy. In case of fire, the steel springs will not fail and release gas, oil or high pressure steam. The alloy-steel springs do not fatigue and lose their accuracy and they withstand abuse better than any other constructions. Numerous illustrations show the details of construction and various application arrangements for different kinds of service. 24 pages and cover, 8½ x 11—Foxboro Company, Foxboro, Mass.

Psychrometers

Psychrometers are ordinarily equipped with two thermometers—a dry bulb for determining the ordinary temperature, and a wet bulb (covered with a wetted wick) for determining humidity. When a wet bulb thermometer is whirled in the air, some of the moisture on the wick evaporates. Heat is required to evaporate water, This heat is obtained from the mercury in the bulb of the thermometer. The wet bulb thermometer will indicate a temperature many degrees below that of the dry bulb. This difference depends upon the amount of moisture in the air. Teltru psychrometers of various types are described in a new folder. A large scale psychrometer chart is included. 8 pages, 8½ x 11—E. Vernon Hill Company, 121 North Clark Street, Chicago, Ill.

Refractory Cements

An interesting bulletin has recently been issued to present the complete line of Ada-products which include refractory cements to meet every industrial furnace condition. Adamant firebrick cement is described as the original high temperature cement. Adachrome is a super-refractory cement for severe conditions and Adapatch is a plastic refractory for quick patching. The Adamant Gun was developed for surfacing and patching firebrick linings. Complete directions for the use of these products are included. 12 pages, 3½ x 6¼—Botfield Refractories Company, Swanson and Clymer Streets, Philadelphia, Pa.

Small Boilers

Catalog A-3 is a loose-leaf binder containing bulletins which describe the Oil City line of small boilers. The Stoker-Unit Firebox boiler is a recent development. This boiler is built in ten sizes from 75 to 300 hp. and for pressures of 15, 100 and 125 lb. It is designed particularly for stoker application and is provided with an exceptionally high firebox to provide added furnace volume. Return tubular boilers of the firebox type, for both stationary and portable service, are also presented. Bulletins covering low pressure heating boilers are also included. 34 pages and loose-leaf binder, 8½ x 11—Oil City Boiler Works, Oil City, Pa.

Steam Specialties

The Wright-Austin line of steam specialties is briefly presented in circular No. 705. The equipment shown includes steam, oil and air separators, steam traps, safety alarm water columns, exhaust heads and feedwater regulators. In addition to this new leaflet, the complete Wright-Austin catalog is available. 6 pages, 6 x 9—Wright-Austin Company, 312 West Woodbridge Street, Detroit, Mich.

Valves, Fittings and Tools

The complete line of Walworth valves, pipe fittings and tools is presented in a comprehensive catalog just issued. The materials available include brass, bronze, cast iron, malleable iron, cast steel, forged steel and a wide range of alloys which are adapted to special conditions, such as, resistance to chemical action, corrosion and erosion at high temperatures. This catalog is a valuable reference book on piping and contains many useful tables of dimensions and general engineering data. 754 pages and cover, 6 x 9—Walworth Co., 60 East 42nd Street, New York City.

NOTICE

Manufacturers are requested to send copies of their new catalogs and bulletins for review on this page. Address copies of your new literature to

COMBUSTION

200 Madison Ave., New York

Boiler, Stoker and Pulverized Fuel Equipment Sales

Total figures to December 1, as reported to the Department of Commerce by the leading manufacturers in each industry

Boiler Sales

	Total 11 mo. 1930		Total 11 mo. 1929		Nov., 1929		Nov., 1930	
	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.
Water tube	1038	5,432,439	1584	9,130,939	102	467,930	63	306,423
H.R.T.	856	1,151,113	1289	1,729,037	76	92,804	60	75,737

Mechanical Stoker Sales

Year and Month	Total		Type of Boiler			
			Fire-tube		Water-tube	
	No.	HP.	No.	HP.	No.	HP.
1929						
Total (11 mo.)	1,637	554,609	676	98,437	961	456,172
Total (year)	1,716	599,585	706	102,515	1,010	497,070
1930						
January	53	13,198	24	2,872	29	10,326
February	73	22,648	26	3,732	47	18,916
March	89	32,403	45	6,128	44	26,275
April	108	35,903	46	6,984	62	28,919
May	96	31,956	41	5,703	55	26,253
June	151	47,803	70	10,100	81	37,703
July	150	37,761	83	11,434	67	26,327
August	115	29,988	61	10,587	54	19,401
September	128	42,899	71	9,186	57	33,713
October	92	38,276	46	5,148	46	33,128
November	71	21,103	41	5,731	30	15,372
Total (11 mo.)	1,126	353,938	554	77,605	572	276,333

Pulverized Fuel Equipment Sales

Year and Month	Central System			Unit System		
	No. of Pulverizers	Total Rated capacity in tons of coal per hour	Total Rated hp. of boilers equipped	No. of Pulverizers	Total Rated capacity in tons of coal per hour	Total Rated hp. of boilers equipped
1930	For Installation Under Water-Tube Boilers					
January	1	6	1,600	52	565	59,742
February	2	20	3,000	29	175	23,305
March	2	50	6,414	16	33	9,995
April	....	....	....	31	139	37,993
May	3	80	11,360	30	196	22,625
June	1	6	802	15	28	7,146
July	2	22	1000	12	29	20,424
August	....	....	....	4	13	1,454
September	....	....	....	24	112	18,729
October	....	....	....	10	16	3,499
November	....	....	....	15	40	7,692
Total (11 mo.)	11	184	24,176	238	1,346	212,604
	For Installation Under Fire-Tube Boilers					
January	....	....	....	6	35	965
February	....	....	....	2	13	305
March	....	....	....	3	3	450
April	....	....	....	3	3	780
May	....	....	....	....	....	....
June	....	....	....	....	....	....
July	....	....	....	....	....	....
August	....	....	....	3	3	712
September	....	....	....	6	3	900
October	....	....	....	....	....	....
November	....	....	....	5	3	641
Total (11 mo.)	....	....	....	28	63	4,753

"You can actually feel the difference!"

So remarkable is the heat insulating quality of STIC-TITE that when an equal thickness of this material is placed next to a covering of asbestos cement the extra insulating value of STIC-TITE can be plainly felt with the palm of the hand. No matter how high the equipment temperature rises the added insulating value of STIC-TITE is always apparent by this simple test.

In customers laboratories, too, engineers have proved conclusively that STIC-TITE has three times the insulating value of common asbestos cement.

Why not order a trial bag of STIC-TITE today?

• • •

FOR BETTER HEAT INSULATION

STIC-TITE is a mineral fiber composition weighing only 16 lbs. per cubic foot as shipped. Being light in weight it will easily cover more than two and one-half times the area covered by an equal weight of asbestos cement. And by covering more area per pound it costs less to use on any job.

STIC-TITE always *sticks!* It clings to *cold* as well as hot surfaces and needs no "heating up" at any time. On the usual job thicknesses of two inches or so, no reinforcement is necessary.

Use STIC-TITE in place of asbestos cement—we'll gladly ship a small order for a trial.

REFRACTORY & ENGINEERING CORPORATION

50 Church Street, New York, N. Y.

Warehouses in Philadelphia, Baltimore, Pittsburgh, Chicago, Boston, Norfolk

R & E CEMENTS—Makers of R & E MOLDIT and #3000

BOOKS *for the* Engineer

1 Mechanical Engineering.

By W. A. Mitchell - 409 Pages - **Price $4.00**

The author covers briefly all subjects of mechanical engineering in chapters on the following: Thermodynamics, fuels and combustion, properties of steam and other gases, steam power, gas power, compressed air, water power, electrical power systems, power transmission, lubricants, refrigeration, heating and ventilation.

2 Practical Heat.

By Terrell Croft - 695 Pages - **Price $5.00**

A book on heat and the practical applications of heat which anyone with a working knowledge of arithmetic can use intelligently. The book discusses fundamental principles of heat, the effects of heat, gas and vapor cycles, combustion, fuels, steam power plants, internal-combustion engine, power plants, refrigeration.

3 Metallurgists and Chemists Handbook.

By D. M. Liddell

3rd Edition - 847 Pages - **Price $5.00**

A thorough revision of this standard reference book of tables and data for the student and metallurgist. The book gives in compact form the most commonly used tables, formulas, constants and reference data. This new edition presents much new material covering chemical and metallurgical progress in recent years.

4 Exhaust Steam Engineering.

By C. S. Darling - 431 Pages - **Price $7.50**

This book is exceptionally rich in material of practical value. Explanations of engineering or scientific principles are brief and clear. The book is of special value as a handbook for the solution of steam plant problems. The subject matter will be as useful in the renovation of old plants as in the design of new ones.

5. Boiler Feed Water Purification **$4.00**
By S. T. Powell

6. Corrosion **6.00**
By F. N. Speller

7. Electric System Handbook **5.00**
By C. H. Sanderson

8. Flow of Hot Gases in Furnaces **5.50**
By Groume

9. Finding and Stopping Waste in Modern Boiler Rooms **3.00**
By Cochrane

10. Fuels and Their Combustion **7.50**
By Haslam and Russell

11. Generating Stations **4.00**
By A. H. Lovell

12. Heat Power **3.50**
By Norris and Therkelsen

13. Mechanical Engineering Laboratory Practice **4.00**
By Shoop and Tuve

14. Mechanical Engineers' Handbook **7.00**
By L. S. Marks. 3d Ed.

15. Mechanical Engineers' Handbook **6.00**
By R. T. Kent. 10th Ed.

16. Materials Handbook **4.00**
By G. S. Brady

17. Power Plant Testing **5.00**
By J. A. Moyer

18. Piping Handbook **5.00**
By Walker & Crocker

19. Steam, Air and Gas Power **4.00**
By Severns & Degler

20. Steam and Gas Engineering **4.50**
By T. E. Butterfield

21. Steam Power Plant Engineering **6.00**
By G. F. Gebhardt. 1928 Ed.

22. Strength of Materials **8.00**
By G. Timoshenko. 2 vols.

23. Structural Engineers' Handbook **7.00**
By M. K. Ketchum

24. Steam and Gas Turbines **15.00**
By A. Stodola. 2 vols.

25. Standard Methods of Chemical Analysis ... **12.00**
By W. W. Scott. 2 vols.

IN-CE-CO PUBLISHING CORP.

200 MADISON AVENUE **NEW YORK**